JOURNAL AND PROCEEDINGS
OF THE

INSTITUTION OF AGRICULTURAL ENGINEERS

VOL. 19 NO. 2 - JULY 1963

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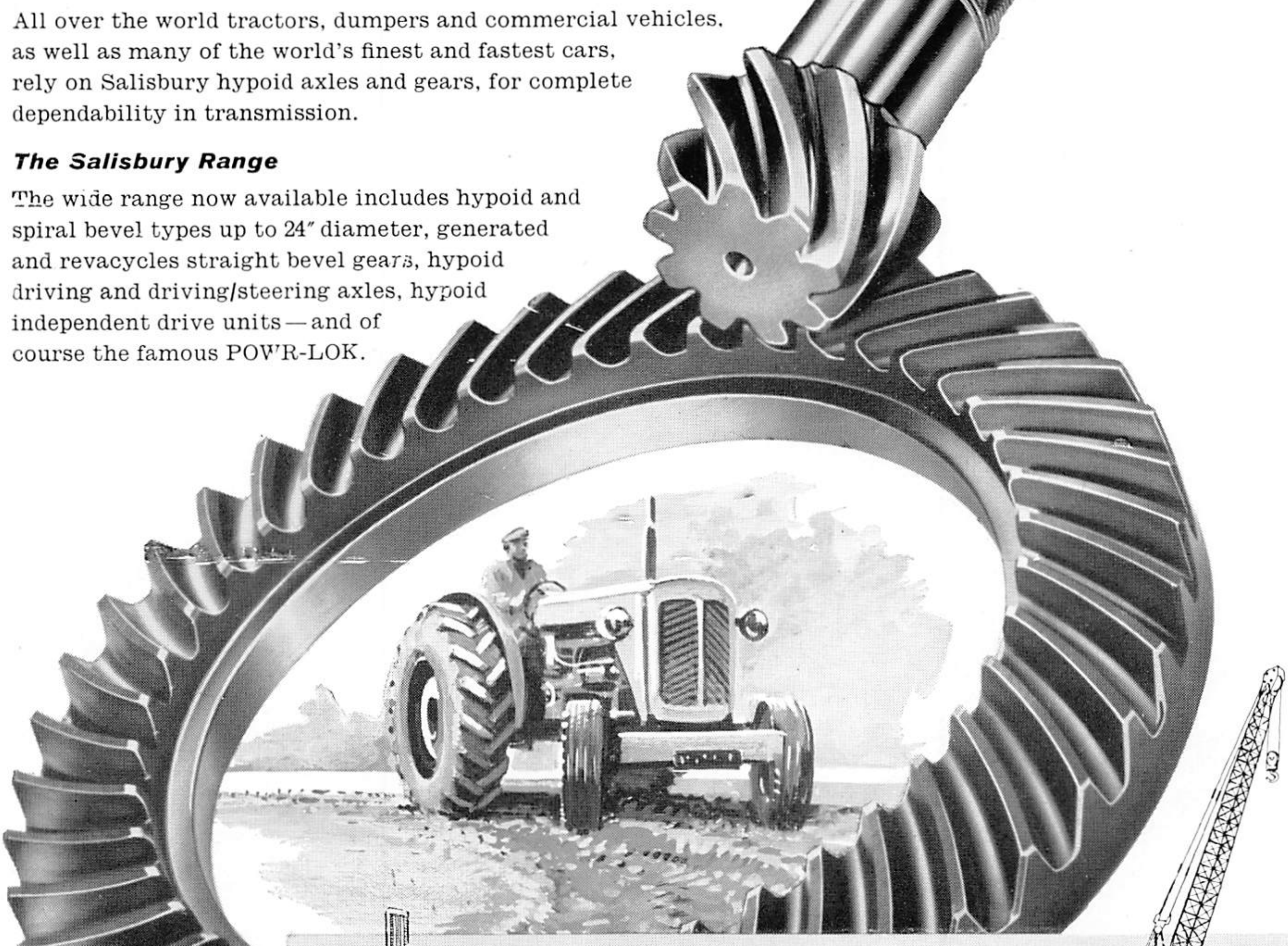

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JOURNAL AND PROCEEDINGS OF THE INSTITUTION OF AGRICULTURAL ENGINEERS

VOLUME 19 - NUMBER 2 - JULY, 1963

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RONALD EDGAR SLADE

Secretary 1951—1963

The news of the death of Mr. Ronald Edgar Slade, the Institution's devoted Secretary, which occurred suddenly on May 17th, has brought sorrow to members throughout the world, and, indeed, to all who had the privilege of knowing him. To his widow, in her overwhelming loss, the Institution proffers heartfelt sympathy.

The many tributes to his life and work which have been received, and the presence of a large congregation at the Memorial Service in the Church of St. George the Martyr, Queen Square, London, W.C. 1, on Thursday, June 6th, are a testimony to the esteem felt for Ronald Slade.

The following appreciation, written by one of the Institution's Past-Presidents, expresses so ably the thoughts of us all about a loyal and lovable friend and colleague.

Ronald Slade's memorial is his great work for the Institution. His dearest wish, it is certain, would be that work shall continue.

W. J. PRIEST

(President).

THE OLD ORDER CHANGETH

RONALD Slade came at a critical point in our history. A small group of men with courage and foresight had founded the Institution in 1938. In 1939 their plans were frustrated by the outbreak of war, and for six years they could do no more than keep it alive. Undeterred, they renewed the development of their project in 1945. It was a difficult task. Funds were insufficient to pay a permanent staff or provide the Institution with a home of its own. A part-time Secretary, necessarily with divided interests, and a shared office were the best that the available income could provide. The Institution was struggling to become a force, but recognition as the acknowledged professional body representing the industry seemed an almost inaccessible goal. This precarious existence continued until 1951, when Council decided that there must be a whole time General Secretary and adequate premises. The decision was reached with some misgiving. Membership was still small and income still insufficient, but it was at this point that the moment was matched by the man.

Slade, quiet, genial and infinitely unassuming, became the Institution's first General Secretary, and it was soon clear that the long years of uncertainty were over.

It is not easy, for those of us who remember the early years of struggle for survival in contrast to the years of achievement which followed, to pay a fitting tribute to the man and his memory. Alexander Hay was the architect of our educational policy, but in the background was Slade, the builder, ensuring that the plans became an enduring structure. So it was with Council and with all the Committees. They could plan with confidence, knowing that their projects would materialise. The presence of one man enabled the Institution to embark on a venture of achievement. The list is impressive. We saw the long-term planning of Papers given to the Institution and the continued improvement in their quality, the beginning of the Institution Journal and the uninterrupted raising of the standard of its contents ; the Year Book, the beginning and further development of the Diploma Examination, the Membership Examination ; the incorporation of the Institution, the initial negotiations leading to the founding of the National College ; two substantial increases in the rates of subscriptions, both of which were welcomed by the members ; the raising of the standard of qualification for membership, the founding of active local branches, an increase in membership from 904 (1951) to 1,873 (1963), the overseas membership, and the establishment of the Institution in its own dignified premises in Queen Square with a loyal and enthusiastic staff. But greater than these concrete achievements is the more abstract one of having enabled the founders and those who joined them in the early years to realise their dream, to see the Institution as a force and to know it as the recognised professional representative of a great industry.

This was Slade, the General Secretary. It is impossible to write of Slade the man without the painful sense of personal loss which so many members of the Institution will be feeling. From the time of his appointment he led a dedicated life. The welfare of the Institution claimed and held him. His personal relationships with individual members contributed largely to the trust and affection which he inspired. Most men can claim only a few intimate friends. Slade had an almost unique capacity for friendship. His natural kindness and honesty were so much a part of him that they grasped the confidence and affection of the men with whom he worked.

The Institution has far to go. It will outlive the lives of men. But in his time he did all that any man could do to set it on its path to greatness.

One epitaph at least is his :

"He did his job."

THE PRESIDENT

Mr. W. J. PRIEST

At the Annual General Meeting of the Institution held on April 25th, 1963, Mr. W. J. Priest was elected President for 1963–64.

Mr. Priest is a native of Essex, where, for generations, members of his family have worked on the land. His career has been spent in technical and trade journalism, and for many years he was on the editorial staff of "The Engineer," specialising in agricultural engineering affairs. When, in 1960, the proprietors of that journal (Morgan Brothers (Publishers), Ltd.) acquired "Farm Implement and Machinery Review," Mr. Priest was appointed Editor.

Mr. Priest was present at the meeting, in November, 1938, when the aims and objects of the Institution were announced to the press. He was first elected to the Institution's Council in 1953, served as Honorary Treasurer from 1957 to 1960, when he became a Vice-President.

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WEAR IN AGRICULTURAL MACHINERY - THE RELEVANCE OF A STUDY OF THE WEAR OF MATERIALS AGAINST BONDED ABRASIVE

by R. D. RICHARDSON*, B.Sc. (Eng.), A.M.I.Mech.E.,

SUMMARY

Some of the forms of wear in agricultural machinery result from conditions peculiar to agriculture, and are therefore of special interest to this industry. A combination of practical experiment and laboratory study is advocated to identify the dominant wear mechanisms. Unpublished field results show that wear on shares is of the type investigated in Russian work employing bonded abrasives. This work is considered in some detail, and discussed in relation to conditions in soil. Various suggestions are made for cases in which this form of abrasion occurs. Attention is drawn to the possible use of materials surface treated by diffusion.

1. INTRODUCTION

1.1. Forms of Wear and the Need for Classification

MANY forms of wear are encountered in agricultural machinery, and some of these are common to machinery generally. Certain forms of wear, however, are of special interest in agricultural engineering, since they are associated with the presence of soil, crop material, fertiliser, etc., or with design practices evolved to meet functional and economic requirements peculiar to agriculture. In these cases the assistance that can be obtained from accumulation of knowledge in engineering generally, depends to a great extent on the ability to identify the principal phenomena which dominate particular wear mechanisms. Some common forms of wear may be considered as examples and placed in tentative groupings.

1. *Metal in soil.* Shares and tines in compact soil, mouldboards and tines in loose soil, discs, rotary cultivator and trench digger blades, crawler track plates, tractor spade lugs, bulldozer blades.

2. *Soil between two metal surfaces.* Crawler track pins and links, root crop elevator chain links, potato elevator digger cone bearings.

3. *Dust (from soil and crop) between two metal surfaces with boundary lubrication or unlubricated.* Plain bearings on wheels, discs, etc., ball bearings, open gearing, sprockets and chains, cutter bar guides.

4. *Bearing seals.*

5. *Metal abraded by vegetable matter.* Milling, pelleting and cubing machine components, cutters and shear bars, grain augers and blowers, ducting.

6. *Plastics abraded by fertiliser.*

Although wear on essential working components is by no means uncommon, such cases are normally regarded as problems only when the service life of the parts becomes sufficiently brief to interfere with the functional operation of a machine, or its economic feasibility. Nevertheless, the true economy to be secured by the reduction of wear must be of great importance due to the certainty and universal occurrence of the direct and indirect costs involved.

1.2. The Sort of Solution Required

The improvement of practical performance normally requires study at least of the entire design of an assembly. The solution of a wear problem in this context may well depend on the selection of materials and the modification of design to secure a better wear performance, without increasing liability to failure or deterioration through other causes, such as impact, fatigue or corrosion.

In the present discussion, however, we are concerned solely with the phenomenon of wear, and in this context a solution must confer some ability to generalise—for instance, by relating wear behaviour to qualities or properties of the materials involved, and of the situation in which this behaviour occurs.

It is well known that mechanisms of wear depend critically on the practical conditions relating to any particular case. Thus two processes are normally required. Firstly, comprehensive and specific information must be obtained from practical trial. Secondly, it is necessary to relate this behaviour at least qualitatively to results observed under controlled and idealised conditions susceptible to analytical treatment.

1.3. The Requirements of a Field Method—Wear on Ploughshares

Considering wear of parts such as ploughshares in soil, the requirements of a method to secure information of the sort that is needed for the present purpose are as follows :

1. A standard material is required against which other materials can be rated so that results are cumulative and can continually be viewed as a whole.

2. The effect of differences in shape (including design differences) should be eliminated when comparing the wear performance of different materials.

3. Test components must be homogeneous within the wear zone so that the observed wear performance relates to a specific material whose mechanical and metallurgical properties may be studied.

* Head of the Metals and Materials Section, Mechanisation Division, N.I.A.E.

4. Field studies should relate to a definable range of conditions. Thus it is necessary to secure a result within an area of land in which the soil type and condition is substantially uniform. Soil properties thought to bear on the wear mechanism must be assessed in order that wear performance should relate to a specific abrasive medium. It is desirable to choose a particular soil for reference purposes for the same reason as in 1.

5. Statistical methods should be employed to determine the precision of the resulting data.

A method satisfying these conditions has been employed by the author in current research at the N.I.A.E., which is not yet ready for publication. Two test implements have been used—a tine on which is mounted a horizontal flat plate test element, cutting edgewise after the fashion of the wing of a ploughshare, and a narrow " chisel ripper " tine inclined at 45° and with a test specimen inserted at the tip. The latter implement is suitable for work in compacted soil at low moisture content.

1.4. Relevance of a Laboratory Investigation employing Bonded Abrasive

Field experiments with these implements have shown that for a wide range of metals and soil conditions, the relative wear rates are in general agreement with results obtained by M. M. Khruschov and M. A. Babichev[1-6] in a study of the wear mechanism resulting from sliding contact with abrasives bonded to cloth or paper. It is considered that most of the phenomena thus far observed in the field can be attributed to effects explored in the Russian work, and since translations are not yet readily available, it is proposed to consider this in some detail in Section 2. The conditions of abrasion in soil in relation to the results of the Russian laboratory study are discussed in Section 3. Some comments and suggestions relating to abrasive wear are given in Section 4, and finally a brief discussion of circumstances in which surfaces hardened to very high levels by diffusion treatment might be employed. For convenience, the wear mechanism described in Section 2 will be referred to as abrasive wear in the remainder of the text.

The material presented in Section 2 is, as far as possible, a direct account of the original work, and the comments and opinions represent those of the Russian authors, with the exception of the comment at the end of Section 2.5 The remainder of the text is the responsibility of the present author.

A great deal of other work has been published (notably that of Wilman[9, 12]) dealing with various aspects of abrasive wear, but it is necessary for the present purpose to limit the discussion.

2. WEAR OF METALS AGAINST BONDED ABRASIVE (Khruschov and Babichev)

2.1. Scope of the Work

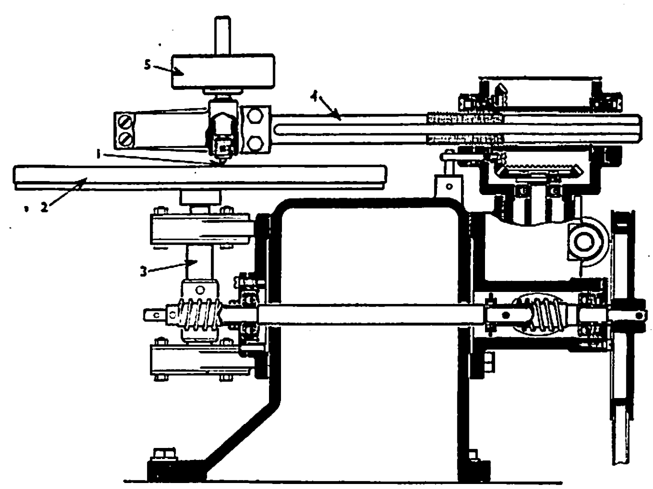
Translations of chapter and section headings given in the periodical *Wear*[2] summarise the scope of this very comprehensive programme of research. Exploratory work was directed to evolving a technique to eliminate unwanted effects, and to isolate a mechanical process of wear in a pure form, which would reflect the influence of innate properties of materials in a continuous and systematic manner. This was followed by studies of the wear resistance of commercially pure metals and steels, and of work hardened metals. A series of investigations were then carried out into special effects, from which the following may be selected for present discussion :

1. The influence of the hardness of the abrasive.
2. The wear resistance of structurally heterogeneous metallic materials.
3. The influence of aqueous solutions.
4. The abrasion of very hard metallic materials.

A considerable part of the remaining work is concerned with exploration of the abrasion mechanism and the formulation of theoretical concepts.

2.2. Technique (Ref. 1 and 3, *N.E.L. Trans.*, 889)

The machine (Kh 4 – B) employed for the tests is shown diagrammatically in Fig. 1. The end face 1 of a cylindrical specimen 2 mm. dia. × 25 mm. long is loaded by dead weight 5 on to an abrasive cloth, mounted on a rotating table 2. Lateral feed is imparted to the specimen holder 4 through gearing 3 from the rotating table drive, and thus the specimen describes a spiral path on the abrasive. Possible extraneous effects may be mentioned briefly.



1 Specimen. 2 Disc. 3 Shaft. 4 Rod. 5 Weight.

FIG. 1.
Machine for abrasive wear testing (Kh 4 – B). (By courtesy of the Institution of Mechanical Engineers.)

Surface Heating

The power input to the wear surface must be limited to avoid a local temperature rise sufficient to affect the properties of the material. This involves limitation of the velocity and load.

Velocity

The velocity varies in the test according to the radius at any instant. It is possible that wear rate might vary with velocity owing to dependence of the mechanical properties of a material upon strain rate. The velocity range chosen should be of a practical order, and it must be shown that no appreciable variation in wear per unit length occurs over the range.

Abrasive

For the present purpose, the abrasive must be of much greater hardness than the materials to be tested. Differential effects with respect to materials may be introduced by clogging, blunting and break away of grains. This difficulty may be largely avoided by applying lateral feed so that the specimen is in contact with fresh abrasive, and by choosing a suitable combination of bond, grit size, contact area and load.

Variation in the wearing capacity of the abrasive may be overcome by the use of a reference material and by testing on each sheet of abrasive with both test and reference materials in a number of sample zones.

Environmental Medium

Most materials form a surface layer which is different in properties and composition from the underlying base material through interaction with the surrounding medium. In order to study the mechanical process of wear of the base material, the rate at which the material is removed must greatly exceed the rate of surface film formation.

Development

Exploratory tests were carried out with low tin Babbitt metal, annealed steel and hardened steel tempered at 150° C., against 170 grit corundum cloth at a load of 0·3 kg, and the wear per unit distance of these metals was shown to be substantially independent of velocity over the range 5·6 to 41·1 m/min. (60-r.p.m.) used in the normal test procedure.

Tests with lead, tin, aluminium, copper and annealed steel were carried out on 170 grit corundum cloth at 60-r.p.m. with loads from 0·1 to 1·0 kg, and a linear relationship was established between wear rate and specific load over a major portion of this range. Divergence occurred at the higher loads due to failure of the specimen (lead) or to mechanical break-up of the abrasive surface (copper and steel). A standard load of 0·3 kg was selected from these results.

Further tests were also conducted to establish the magnitude of the reduction in wear rate due to repeated friction over the same area of abrasive. It was thus established that the 1 mm. (D/2) lateral feed adopted in the normal procedure was sufficient to render this factor negligible.

Standard Method

In the technique finally adopted, the spiral path on the abrasive surface is divided into 10 zones each of length 3 m. The test specimen and standard are tested on alternate zones, giving each a total wear path of 15 m. The specimens are rotated through 90° in passing from one zone to another to reduce the effect of directional properties. Corundum cloth was normally used of 180 grit*, a load of 0·3 kg, and a speed of 60-r.p.m. (5·6 to 41·1 m/min.). Corundum was replaced by specially hard abrasive for test materials of extreme hardness, and the run length was increased when necessary.

The volumetric wear is measured either as the loss in weight divided by the density, or the reduction in length. The run length is chosen so that an accuracy of $\pm 4\%$ can be achieved weighing to $\pm 0{\cdot}1$ mg. or measuring to $\pm 4\mu$ (one $\mu = 0{\cdot}001$ mm.). Statistical analysis indicates that overall repeatability is in the region of $\pm 4\%$.

In order to allow for variation in the wear produced by different samples of abrasive cloth, the wear of the test material is related to that of a standard.

$$\text{Relative wear resistance } \varepsilon = \frac{\text{volumetric wear of standard}}{\text{volumetric wear of material}}$$

This is a reciprocal of the volumetric wear, standardised and at the same time expressed in dimensionless form. In practice, specimens vary slightly from the nominal diameter of 2 mm., and since it is shown that the linear wear is proportional to the specific load (*i.e.*, $\delta l = cp$),

$$\varepsilon = \frac{\delta l_s}{\delta l}\left(\frac{d_s}{d}\right)^2 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where δl = reduction in length.
d = specimen diameter.
Suffix s refers to the standard.

In terms of weight loss,

$$\varepsilon = \frac{\delta W_s \rho}{\delta W \rho_s} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where δW = weight loss.
ρ = specific gravity.

The standard material used in this study was a tin–lead alloy and this appears as unity on the relative wear resistance scale.

2.3. The Wear Resistance of Commercially Pure Metals and Steels (Ref. 1 ; 4, *N.E.L.Trans.*, 831; and 5)

A unique relationship was found between relative wear resistance and indentation hardness for annealed pure metals and steels. The wear resistance and hardness are substantially in direct proportion (Fig. 2). The relationship for hardened and tempered steels (Table I and Fig. 2) is dependent upon composition. It is found that wear resistance is almost unaffected when metals are work hardened prior to abrasion (Table II and Fig. 3). This is attributed to the formation of a residual work hardened layer on the wear surface, of sufficient depth to determine the wear performance. This layer is assumed to be formed on both the unstrained and the work hardened metals, and if the hardness level thus achieved is sufficiently high, prior hardening to a lower level will produce no effect. In support of this conclusion, it is shown[6] that high strain properties such as ultimate tensile strength, plot against hardness in a generally similar manner. It is to be noted that studies on a range of bearing alloys of heterogeneous structure indicated that such materials do not show the linear relationship applicable to annealed pure metals and steels. Thus a knowledge of the structure is necessary in using the present data to predict results on materials not yet studied.

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* 180 grit mainly 80μ.

Table I

WEAR RESISTANCE OF COMMERCIALLY PURE METALS, AND STEELS

Material	*Diamond pyramid hardness, $H_d Kg/mm.^2$*	*Relative wear resistance ε*	*Material*	*Diamond pyramid hardness, $H_d Kg/mm.^2$*	*Relative wear resistance ε*
W	425	58·4	Steel 40 Annealed	162	22·4
Be	320	43·7	Steel 40 Quenched	720	37·6*
Mo	282	38·3	Steel U8 Annealed	186	25·5
Ti	248	33†	Quenched and Tempered	240	27·1
Cr	221	30·1		286	28·3
Co	145	20·1		468	33·8
Fe	140	19·3*		615	38·2
Ni	109	15·2		795	43·8
Cu	74	10·0	Steel U12 Annealed	210	28·4*
Zn	43	6·3*	Quenched and Tempered	840	50·7*
Al	21·7	3·64	Steel Kh 12 Annealed	220	30·2*
Cd	20	2·9*	Quenched and Tempered	835	57·9*
Pb	8	0·8*			

Steel 40 0·41% carbon steel.
Steel U8 0·83% carbon steel.
Steel U12 1·10% carbon steel.
Steel Kh12 2·35% carbon, 11·9% chromium steel.

* Scaled off graph Ref. 5.
† Scaled off graph Ref. 1.

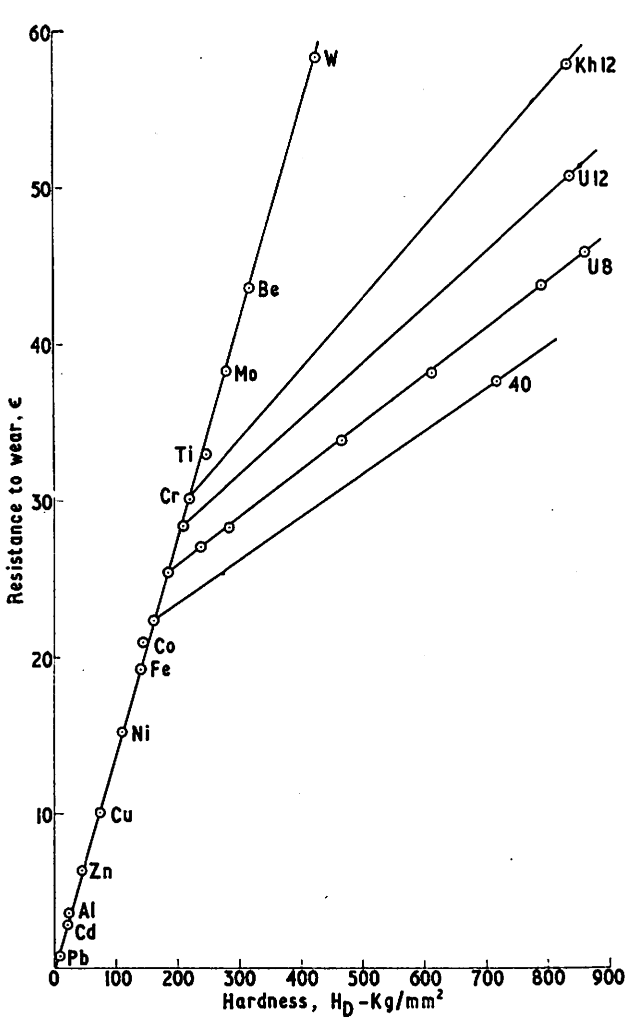

FIG. 2.
ε–H graph for annealed commercially pure metals and steels, and hardened and tempered steels.

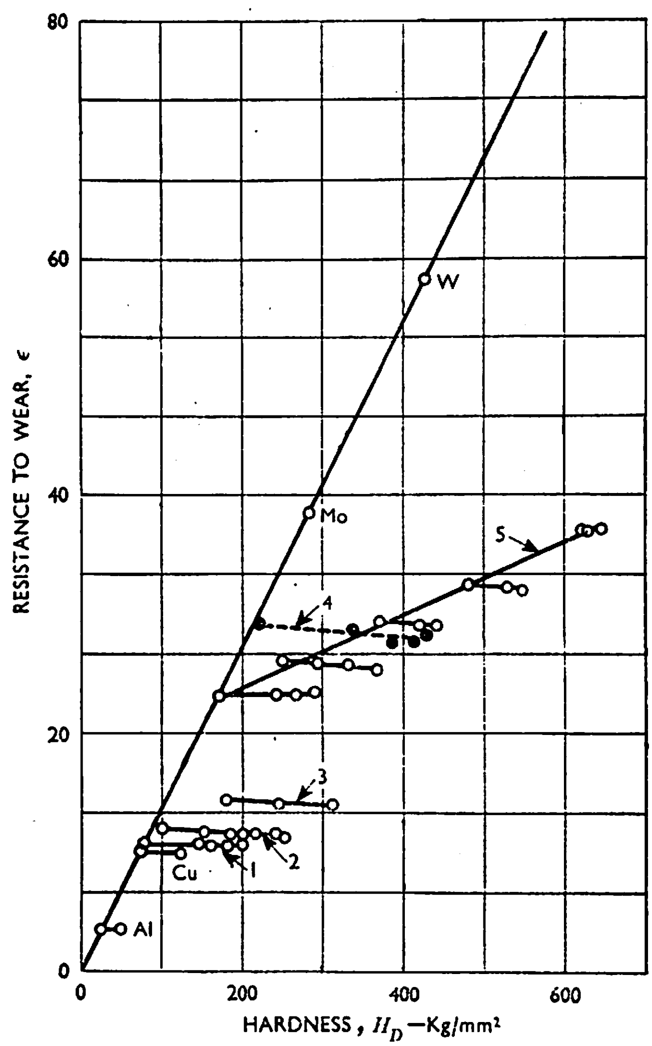

FIG. 3
ε–H graph for cold-worked materials. (By courtesy of the Institution of Mechanical Engineers.)

Table II
WORK HARDENED METALS

Material	*Nominal composition*	*Condition before cold working*
1. Brass	80% Cu, 20% Zn	Annealed
2. Al. Bronze	95% Cu, 5% Al.	Annealed
3. Be. Bronze	2% Be.	Quench annealed
4. Austenitic S.S.	0·2% C, 18% Cr, 9% Ni	Quench annealed
5. Carbon steel	0·4% C	Annealed
Carbon steel	0·4% C	Quenched and tempered

2.4. The Influence of the Hardness of the Abrasive

(Ref. 4, *N.E.L.Trans.*, 830)

The results given in Section 2.3 refer to the normal test condition in which the abrasive is much harder than the materials under test. A separate study was made in which this factor was varied.

A 0·83% carbon steel was hardened and tempered to obtain specimens ranging in hardness from 186 to 795 kg/mm². Two types of corundum abrasive sheet were employed having grit sizes of 170 and 180, and a glass paper of grit size 180. The micro indentation hardness of the abrasive grains was determined at loads of 100 g. and 50 g. for corundum and glass, giving values of 2,290 and 585 kg/mm.² respectively. Abrasion test results (Fig. 4 and Table 3) show that the normal hardness –wear resistance relationship is obtained on corundum of both grain sizes (though the absolute wear values differed by 25%), and on glass for the softer steels. A sharp increase in wear resistance occurs as the hardness of the metal approaches that of the glass. Two points may be noted, however. Firstly, the wear resistance starts to increase when the hardness of the undeformed metal is still substantially lower than that of the abrasive. This is consistent with the presence of a work hardened surface layer on the metal. Secondly, some wear is still experienced when the hardness of the metal exceeds that of the abrasive. This is presumed to be due to the known ability of a conical particle to scratch a flat surface of the same hardness in certain circumstances.

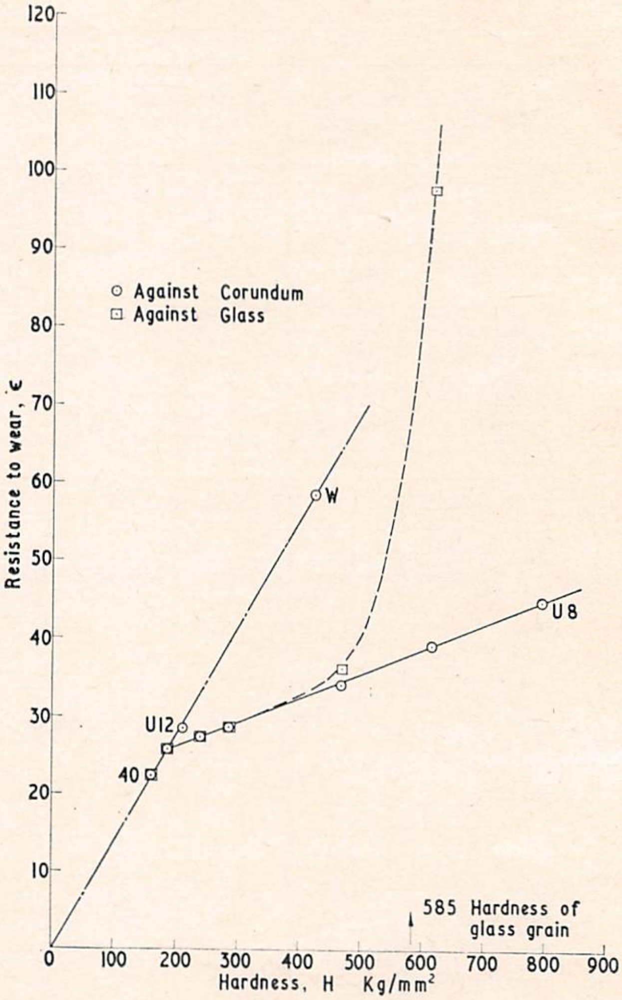

FIG. 4.
The effect of the relative hardness of the abrasive on resistance to wear.

2.5. The Wear Resistance of Structurally Heterogeneous Metals (Ref. 4, *N.E.L.Trans.*, 828)

Tests with Babbitt metals against a smooth steel surface revealed different intensity of wear for the soft matrix and hard phases, resulting in the surface layer becoming richer in the latter. This is not observed during abrasive wear of the type now considered. It is

Table III
WEAR RESISTANCE AGAINST CORUNDUM AND GLASS

Material	*Condition*	*H* *Kg/mm.²*	*Relative wear resistance ε* 170 *grit corundum*	180 *grit corundum*	180 *grit glass*
Steel 40	Hot rolled	162	22·4	22·4	22·4
Steel U8	Quenched and tempered	795	43·8	44·3	586·9
,,	,,	615	38·2	38·5	97·8
,,	,,	468	33·8	34·0	36·1
,,	,,	286	28·3	28·6	28·6
,,	,,	240	27·1	27·3	27·3
,,	Quenched, tempered 790° C.	186	25·5	25·7	25·7

therefore assumed that the intensity of wear on different phases is constant and that this results from redistribution of the load among individual phases. For specimens of equal diameter on the same abrasive and at given length of run,

$$\varepsilon = \frac{\delta l_s}{\delta l} \quad \text{where } \delta l_s = c_s p \text{ for the standard}$$

and $\delta l = c_t p$ for the test material.

Since linear wear δl on all phases and the whole is identical,

$$c_1 p_1 = c_2 p_2 = c_r p_r = c_t p \quad . \quad . \quad . \quad (3)$$

where the suffix 1, 2 -- r applies to phase 1, 2 -- r, etc.

q = proportion by area of a given phase on the wear surface. Since δl is common, q also equals the proportion of the phase by volume.

$$p = \Sigma p_r q_r \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\varepsilon = \frac{c_s p}{c_t p} = \frac{c_s \Sigma p_r q_r}{c_r p_r} = \Sigma \varepsilon_r q_r \quad . \quad . \quad (5)$$

Thus if the assumptions are correct the relative wear resistance of the whole is given by the sum of the relative wear resistance of each phase multiplied by its proportion by volume.

This conclusion was checked by a variety of tests.

1. Tests on porous material prepared from copper and from iron powder, at varying degrees of porosity, giving phases of copper and void and of iron and void respectively—$\varepsilon \alpha$ proportion of the metal.

2. Tests on brass specimens having longitudinal holes drilled in them and filled with lead. The numbers of holes were varied to give different proportions of the two metals—ε ranges linearly from that of lead to that of brass according to the pıoportion of the two metals.

3. Tests on aluminium-silicon alloys ranging from pure aluminium to pure silicon, considering particularly the hypereutectic range with over 15% Si, in which the silicon phase has a wear resistance four times that of the eutectic —ε ranges linearly from that of the eutectic to that of silicon according to the proportion of the two phases.

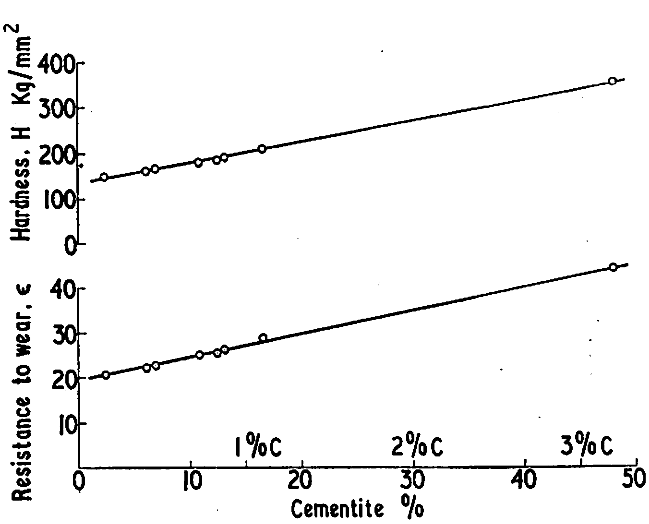

FIG. 5.
Relative wear resistance of pearlitic carbon steels and iron.

Table IV
WEAR RESISTANCE AND HARDNESS OF PEARLITIC STEELS AND IRON

Material	*Carbon %*	*Cementite %*	*H kg/mm.²*	ε
Armco Iron	0·02	—	140	19·4
Carbon Steel	0·16	2·40	150	20·7
,,	0·41	6·15	163	22·4
,,	0·46	6·90	169	22·7
,,	0·72	10·80	181	25·1
,,	0·83	12·45	186	25·5
,,	0·87	13·05	193	26·1
,,	1·10	16·50	210	28·8
White Iron, 1·07% Si	3·20	48·0	354	44·4

4. Tests on annealed carbon steels, armco iron and 3·2% C white iron, presumably pearlitic.

In all cases the additivity rule of equation (5) was shown to be valid, and in the case of item 4 above a similar relationship was shown to hold between the Vickers hardness and the proportions of the two phases (Table IV and Fig. 5). It is considered by the authors, however, that further investigation is required of the conditions for validity of these relationships.

Comment

Although it is not specifically stated, this recommendation may be due to the low value of wear resistance for the carbide (cementite) phase calculated from the results of Fig. 5.

According to the gradient of the curves,

$$\varepsilon_t = 19{\cdot}2 + 52\, q_2$$

where q_2 = proportion by volume of cementite
and 19·2 = ε_1 for ferrite.

Putting $q_2 = 1$,

$$\varepsilon_2 = 19{\cdot}2 + 52 = 71{\cdot}2 \text{ for cementite.}$$

Assuming that the hardness of cementite is about 1,000 kg/mm.², it can be seen from Fig. 6 that this value is unexpectedly low (see also Section 2.7). The authors point out that the effect of size of individual structural components has not been investigated. This also applies to their shape and spatial distribution. It is notable that the pearlitic (annealed) carbon steels tested against glass (Section 2.4 and Fig. 4) showed no effect due to the hardness of the cementite phase greatly exceeding that of the glass. It is thus difficult to escape the conclusion that cementite present in pearlite does not behave in the standard test as a discrete material as required by equation (5) ; at any rate, when the abrasive is relatively soft. On the other hand, the linearity of all the results in Fig. 5 would support the contention that cementite present in pearlite contributes to wear resistance to the same extent as when it is present as massive carbide in white iron.

2.6 The influence of Aqueous Solutions (Ref. 4, *A.S.M.E. Trans.*)

Tests were carried out to determine the effect of water and of dissolved contaminants in water on wear, especially abrasive wear. For this purpose, tests were carried out with a second type of apparatus, Kh 2 – M, as well as with an adaptation of the abrasion test machine Kh 4 – B previously used.

Preliminary Tests on Kh 2 – M Machine

This machine consists of a vertical shaft carrying a hard alloy disc, 46·31 mm. D × 0·95 mm. thick, at its lower end. The disc is rotated at 570-r.p.m. and its edge, which is diamond lapped, wipes a cavity on the flat surface of a specimen under an applied load of 1·9 kg. The volume of the cavity is measured from the length of the impression after 2,000 revolutions of the disc. Both the disc and test specimen are immersed in the required fluid medium at constant temperature. Results on a carbon steel (steel 35 at 188 BHN) and a stainless steel (steel 18 Kh 9 N at 400 BHN) in various aqueous media at 30° C. (Table V) show very pronounced differential effects according to the contaminants present. Further tests show that completely different results are obtained with solutions whose pH is varied by addition of HCl or NaOH, according to the source of the water supply. Thus wear phenomena of this type are dependent upon the nature of the contaminants, as well as upon the pH of the solution.

Table V
WEAR RESISTANCE AGAINST A METAL DISC IN THE PRESENCE OF AQUEOUS MEDIA

Origin of water	Storage time, hours	Vol. wear $V \times 10^3$, mm.³		Wear resistance (relative to the carbon steel) ε_1
		Carbon steel	Stainless steel	
River	1·5	0·52	1·71	0·302
	48	1·32	1·30	1·01
	120	5·51	11·5	0·48
	240	9·73	2·96	3·30
Water supply	1·0	0·43	2·09	0·206
	48	1·43	1·24	1·15
	246	0·48	0·72	0·66
Distilled	1·2	14·7	0·32	46·0
	24	14·6	0·32	45·6
	72	14·5	0·32	45·3
	120	14·3	0·33	43·4
	5,712	13·9	0·36	38·6
0·5% solution of K_2CrO_4	1·2	13·2	5·59	2·36
	5,712	14·7	4·28	3·44

Abrasion Tests on Kh 4 – B Machine

The Kh 4 – B abrasion test machine was fitted with a rather smaller rotating table, having a raised shoulder around the circumference so that a water film could be maintained over the abrasive surface. Water-resistant abrasive paper was used and tests were conducted both wet and dry (Table VI). It appears that the presence or otherwise of a water film has little effect either on the absolute wear rate or the relative wear rate of this range of steels, the largest effect being a 30% increase in the wear resistance of LG 13 (Hadfields steel) in the presence of water. Further tests with a ploughshare steel were carried out in water of varying pH on standard 180 grit corundum and on very fine grit carborundum, the latter at standard load and at 0·1 kg. In all cases the effect of pH was negligible.

Table VI
WEAR RATIO AGAINST BONDED ABRASIVE, DRY AND WET (with distilled water)

Steel	Condition	Vol. wear, dry / Vol. wear, wet
0·45% C (45)	Hot rolled	1·14
	Quenched and tempered	1·08
1·10% C (U12)	Annealed	1·02
	Quenched	0·96
(RF1)	Annealed	1·04
	Quenched	0·93
Hadfield (LG13)	Quench annealed	1·31

This independence of pH and of the presence or absence of a water medium in the case of abrasive wear is attributed to the high intensity of wear in this type of abrasion. The mean wear rate on the Kh 2 – M smooth disc machine was 0·022 μ/m for a hardened ploughshare steel compared with 11·3 μ/m on the standard abrasion test and 1·1 μ/m with fine abrasive and 0·1 kg load. The wear intensity is thus 50 times as great even for very mild abrasion and 500 times as great in the standard Kh 4 – B test.

When the wear intensity is very low, as in the tests against a smooth, hard disc, the properties of the water medium have a strong effect. From this result it is suggested that such wear is dominated by the properties of the film formed on the surface of the metal by interaction with the medium, and not by the mechanical properties of the base metal. When the wear intensity is higher, as in abrasive wear, the effect of the water medium is normally negligible. The bulk of the metal removed is taken from the interior and governed by the properties of the base metal. It is suggested that in these circumstances the thickness of the chemically-active surface zone is too small to be of significance.

A few figures are quoted for wear intensity on various parts of ploughshares, 0·002 to 0·18μ/m, and the opinion is expressed that wear rates on some parts of ploughshares are probably affected by the soil solution, whereas cutting edges are probably not so affected.

It is pointed out that great care must be exercised if laboratory methods are designed to study wear experienced under particular service conditions, since, for example, the time of storage and source of the water in the Kh 2 – M tests was of critical importance.

2.7. The Wear of Very Hard Metallic Materials
(Ref. 4, *N.E.L.Trans.*, 831)

Hard Electroplated Chromium

A layer of chromium 0·15 mm. thick was deposited on the end of 2 mm. diameter test pieces of 0·7% carbon steel. These were tempered to produce a film hardness ranging from 1,005 kg/mm.² (no temper) to 395 kg/mm.² (750° C.). Abrasion test results on fine grit carborundum (Fig. 6) show nearly direct proportion between relative wear resistance and hardness, and correspond fairly closely with the relationship for annealed pure metals and steels.

Table VII
WEAR RESISTANCE OF MATERIALS OF HIGH HARDNESS

Material	*Description*	*Hardness H.Kg/mm.*[2]	*Relative wear resistance ε*	*Abrasive*
VK 6	Metal carbide—cobalt compact	1,950	80·2	Not stated ;
VK 8	,,	1,510	70·6	probably
VK 15	,,	1,110	61·8	carborundum
TD Kh	Steel 0·65% C, chromised	1,650	227·5	
Tungsten	Cast, eutectic	2,520	330·7	Boron carbide
Carbide	Same	2,522	332·8	,,
	Cast, hypoeutectic	2,290	157·2	,,
	Cast, hypereutectic	2,405	206·9	,,
EB Armco Iron	Boronised	1,413	134·2	Carborundum
EB Steel 10	,,	1,560	121·9	,,
EB Steel L65	,,	1,680	132·9	,,
EB Steel U8	,,	1,680	136·6	,,
Silicon	Grade Kr.2	1,225	14·7	,,

Very Hard Materials

Abrasion tests were carried out on a variety of very hard materials (Table VII, Fig. 6).

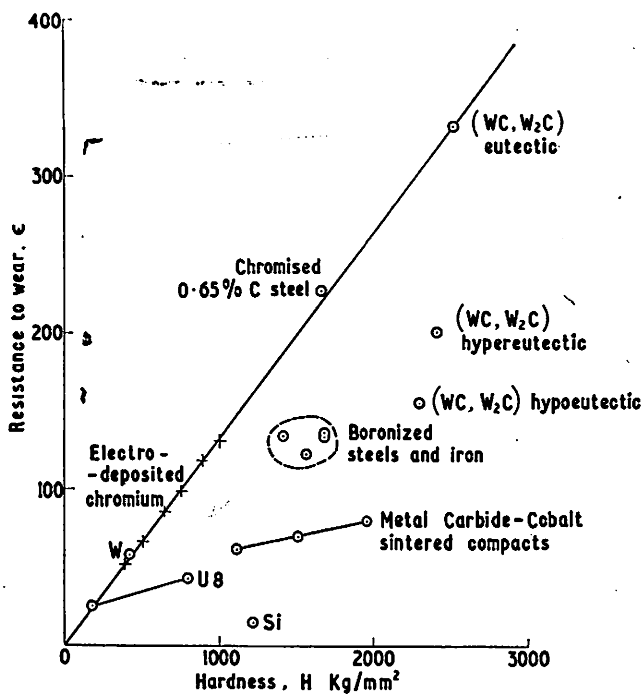

FIG. 6.
ε–H graph for materials of high hardness (and electroplated chromium).

Special abrasives were used in some cases (Table VIII) to satisfy the standard test condition that the hardness of the abrasive should be substantially greater than that of the material under test.

Table VIII
ABRASIVES USED TO TEST HARD MATERIALS

Abrasive	*Load on Indenter gm.*	*Diamond pyramid hardness Kg/mm.*[2]
Electrocorundum	100	2,290
Carborundum	100	3,020
Boron carbide	50	5,250

The VK materials in Table VII were superhard alloys bound with cobalt and are presumably sintered tungsten carbide-cobalt with varying proportions of cobalt. The TD Kh material was treated by diffusion of chromium from the gas phase, and core ground with boron carbide to produce the specimen. The cast tungsten carbides were centrifugally cast. The EB materials were boronised electrolytically, using iron and steels varying in carbon content.

As shown in Fig. 6, the chromised material TD Kh and the eutectic cast tungsten carbide behave substantially as annealed pure metals and steels, showing that the same proportionality with hardness applies to some carbides up to very high hardness levels (*cf.* cementite, Section 2.5).

The boronised materials, EB, all gave a result independent of the initial carbon content, the surface hardness being due primarily to iron boride.

The reasons for the low relative wear resistance of the EB materials, the hyper and hypoeutectic cast tungsten carbide, and of the silicon, are not fully understood and require explanation.

2.8. Resistance of Minerals to Abrasion
(Ref. 3, *N.E.L.Trans.*, 891)

A further study of the wear resistance of minerals tested on the Kh 4 – B machine by the standard method is of interest. The gradient of the ε – H graph for annealed pure metals (Fig. 2) is 0·137. That for germanium and silicon is 0·012, which compares with a value 0·014 for the majority of minerals. The relative wear resistance of most minerals and of these two borderline metals is thus only about a tenth of that of the annealed pure metals at corresponding hardness.

A further test is quoted in which relatively very haıd granular abrasive was rubbed between blocks of quartz and of minerals under test. The relative wear resistance can be expressed in the same way as in the present work, taking quartz as the reference material. The results show very good agreement with those obtained on the Kh 4 – B machine. This conformity between a test in which the abrasive is fixed and one in which the abrasive is free to roll suggests that the essential features of the abrasive wear mechanism may occur over a range of different conditions.

2.9. **Theory** (Ref. 3, *N.E.L.Trans.*, 892,893)

It is not the present intention to give a full account of the theoretical aspects of the study. However, it may be of interest to comment briefly on some conclusions drawn from scratch testing. In the Bierbaum scratch hardness test a diamond point is used, ground to the shape of the corner of a cube with the body diagonal vertical. The point is loaded to 3 gm. and drawn across a flat specimen with one edge of the cube leading. The width of the scratch then provides a measure of hardness.

In the present study the diamond point was also drawn in the opposite direction, with a facet leading, and the load was varied. When scratching in the normal direction, metal piled up on each side of the scratch, but no turning was produced. When scratching with the facet leading, a turning was produced. In the latter case, the hardness based on the scratch width and load was found to be independent of the state of work hardening of the metal and the load. Thus when the orientation of the point is such that metal is removed, the section of the scratch, and hence the amount of metal ploughed out, is the same whether the metal is annealed or hardened by cold work. This agrees with the fact that the relative wear resistance is the same for annealed or work hardened metals.

An argument is then developed to suggest that in friction against bonded abrasive, the majority of the scratches are impressed line scratches which contribute to the work hardening of the surface, but which do not remove material. A minority of scratches produce turnings where the orientation of the facets of the abrasive grains is favourable to cutting.

3. ABRASIVE CONDITIONS IN SOIL

Abrasion in soil differs from conditions in the Khruschov–Babichev test in several respects :

1. The presence of moisture and a soil solution.
2. The abrasive is to some extent unbonded so that particles may roll as well as slide.
3. Frictional heating may occur under some conditions.
4. The tangential velocity may vary widely.
5. The local wear intensity and contact pressure may vary very widely and are generally very variable with respect to time.
6. The particle size is composite and covers a very wide range.
7. The hardness of the abrasive is variable and composite and may be dependent upon contact pressure.
8. The loading and motion of the soil particles may depend on the friction at the wear surface.

Moisture and Rolling of Particles

Results obtained by Weiss[7], using a cast-iron disc rotating in a horizontal plane and fed with abrasive in a water slurry, can be expressed in terms of relative wear resistance, and show relationships similar to those obtained by Kruschov and Babichev. This supports the view that abrasive wear is dominant over a fairly wide range of conditions, and that rolling and the presence of moisture do not necessarily produce important changes in the wear mechanism.

Frictional Heating

Frictional heating may well occur in hard, dry soils, and this possibility can be explored by comparison of materials with a large differential temperature response in wet and dry soils.

Velocity

The velocity range covered by the standard tests on dry bonded abrasive (Section 2.2) was 0·3 to 2·25 ft./sec. Tests on the Kh 4 – B machine at four times this speed —that is, up to 9 ft./sec.—showed little variation.

Wear Intensity

It is possible that where the wear intensity is very low, mechanical abrasion may cease to dominate, as suggested in Section 2.6. However, the value of the average wear intensity is not a sufficient criterion if it is made up largely of brief wear increments of high intensity resulting from intermittent contact with stones. Other wear mechanisms may also produce major effects at high contact pressures due to macro failure of the material, such as the chipping or crushing of an edge.

Complexity of the Abrasive

Due to the composite nature of soil, some portion of the potentially abrasive matter is in general softer and some harder than the wearing material. Thus the advantages to be gained from the use of harder materials are somewhat greater than in the case of a uniformly very hard abrasive. A further complicating factor is that contact occurs primarily with the outer layers of soil particles, which may have physical properties very different from those of the underlying material. If the surface layers of the abrasive particles are ruptured due to high contact pressure, contact is made with an effectively different abrasive. Thus the relative wear performance of a metal containing a very hard phase may be different, even in a particular soil, according to the soil strength (*i.e.*, moisture content, state of cultivation), when compared with a material lacking such a phase. The size of the soil particles and that of the structural constituents of the wearing material may also introduce differential behaviour. Scale effects such as this might also vary with contact pressure.

Surface Loading and Motion

The loading and motion of the soil particles is not controlled as in a laboratory test against bonded abrasive, and if these factors are affected substantially by the frictional conditions at the wearing face, this might introduce a major difficulty in inter-relating field and laboratory studies. Field studies carried out at N.I.A.E. with wearing elements of two different shapes gave virtually identical relative wear results for a range of materials which were, in turn, generally consistent with those of Khruschov and Babichev. It appears, therefore, that the indirect effects of soil-metal friction on the wear of practical components are not important, at least in moist, stony soils, or when the velocity distribution around the wearing object is determined principally by the requirements for continuity of flow.

* * *

It is clear from Section 2 that major effects are likely to arise when the hardness of the abrasive or some portion of it falls to a level approaching that of the wearing material or some of its constituents. In current N.I.A.E. work, substantial variations in relative wear resistance from one soil to another have so far been found to occur only with metals containing massive carbides, and this behaviour is at present thought to be due to the relative hardness effect. It is hoped to confirm whether or not this is the case.

4. COMMENTS AND SUGGESTIONS RELATING TO ABRASIVE WEAR

4.1. Tests for Relevance of the Abrasive Wear Mechanism

Much experimental work is required to determine the circumstances under which abrasive wear can be expected to dominate wear performance. Conclusions from the results presented here must therefore be applied with caution until such classification has been effected. From the results shown in Fig. 2, however, it should be a relatively simple matter to test for the applicability of the abrasive wear mechanism by comparing a small number of very different materials. A suitable selection might include six materials. If high strength is required in the component being considered, the selection would have to be made from the harder materials. In any event, it would be particularly useful to include a corrosion-resistant material, a stainless steel or electro-deposited chromium, and a rapidly work hardening material such as austenitic manganese steel. The remaining materials would be chosen for diverse structure, response to high temperature, hardness and perhaps carbon content.

4.2. Some Practical Conclusions in Cases of Abrasive Wear

The first notable feature of the Khruschov–Babichev study is the relatively poor increase in wear resistance over that of more usual materials, obtainable even through the use of a high carbon alloy steel (such as 2% carbon, 12% chromium die-steel). The slight advantage conferred by the appreciable content of chromium, as well as the additional carbon, suggests that the effect of small additions of alloying elements, as in low alloy steels, on resistance to this type of abrasion is probably negligible. This has been confirmed in N.I.A.E. work in soil, where the wear resistances of EN 8 and EN 24 (both steels containing 0·4% C) at the same hardness, were found to be identical. It is therefore evident that the use of more expensive low alloy steels must be justified by factors other than wear resistance ; for example, ability to harden throughout in heavy sections, or increased resistance to shock or fatigue. The low gain in wear resistance for an increase in the hardness of a material accounts for the difficulty experienced in designing truly self-sharpening ploughshares.

The most promising effect for exploitation appears to be the use of material having higher effective hardness than that of the abrasive. Such material may either be applied directly, or as a surface layer, or as a constituent or phase in a heterogeneous structure. N.I.A.E. results in soil suggest that the effective hardness of the iron carbide in unalloyed white iron exceeds that of many soil constituents, and also that the size and severity of the scratches imposed during abrasion, in relation to the size of the structural elements of the metal, may be of importance. The hardness of quartz, or silica, is normally estimated at about 1,200 kg/mm.^{2}, but the hardness of mineral material sampled from agricultural soils has not yet been studied in detail so far as is known.

The advantage to be gained from hard or cast materials suggests the use of inserts. There may also be a need for more precise specification and control of cast structures, and more precise means of determining and specifying their impact properties.

4.3. Suggestions for Further Laboratory Study

Apart from further fundamental study of the abrasion process, an extension of the work reported by Khruschov and Babichev is required to give more adequate guidance in the solution of practical problems.

1. *The influence of the hardness of the abrasive.*

The effective hardness of abrasive matter normally encountered in agriculture should be established so that comparable abrasives can be selected for test purposes.

2. *The wear of materials harder than the abrasive.*

Wear still takes place when the abrasive is relatively soft, and this wear regime requires investigation, with particular reference to the influence of aqueous solutions.

3. *The wear resistance of structurally heterogeneous materials.*

An extension of the work already reported is required (*a*) to determine whether the relative wear resistance of a constituent or phase, determined from equation (5), always corresponds with the value determined directly from a homogeneous specimen ; (*b*) to investigate further the validity of the additivity law, testing for effects due to scale or distribution.

A new study is required to investigate the validity of the additivity law and the occurrence of new qualitative effects when the effective hardness of a phase or constituent exceeds that of the abrasive.

4. *The abrasion of very hard materials and minerals.*

The wear resistance of certain very hard materials requires explanation and information is required of (*a*) promising materials for application direct or as surface treatments ; (*b*) materials that might be incorporated as a phase of a practical material by means such as powder metallurgy. This group might include minerals such as alumina.

5. *The wear performance of metals of very high strength or toughness.*

Since the principal effect in this type of abrasion appears to be work hardening of the wear surface, an evaluation of vacuum melted high-purity metals, of high strength " whiskers " incorporated in a bond, or of diffusion treated surfaces, would be of interest.

4.4. Use of Wear Solutions in Experimental Techniques

Examination of worn components frequently stimulates the impression that the distribution of wear is systematic and of considerable physical significance. The distribution of wear (for example, on worn gears) is commonly used in qualitative diagnosis of mechanical faults. The conclusion can hardly be escaped that the distribution of wear on a hammermill fan blade conveying milled dried grass (Fig. 7) is evidence of the motion of the particles in the flow.

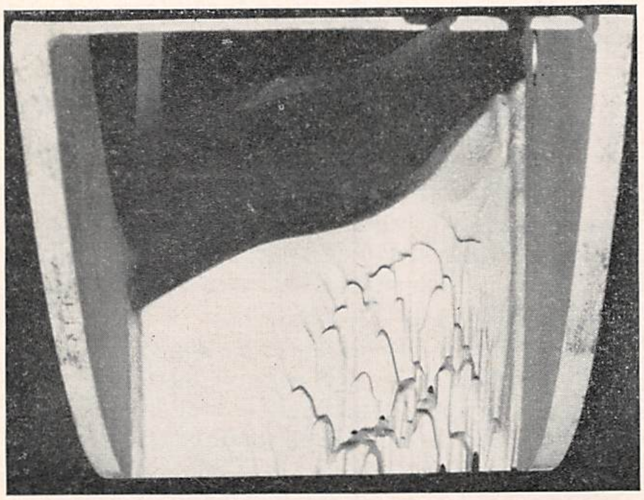

FIG. 7.
Hammermill fan blade worn by dried grass (N.I.A.E. photograph).

It has been shown by several workers [3,8,9] that under conditions similar to those in Section 2.2—*i.e.*, absence of heating, relatively hard abrasive, etc.—the linear wear at a point is proportional to the length of the wear path and the specific load. It follows that when these conditions are satisfied and subject to possible limitations on velocity and specific load, the wear at a point on a body is proportional to the product of the local tangential velocity of the abrasive relative to the body and the stress normal to the surface (*i.e.*, specific load) at that point.

In cases where the appropriate wear mechanism has been shown to apply, as with many common materials in soil, a tentative solution of the distribution of normal stress could be obtained from a knowledge of the velocity field and the local wear intensity. This method would be most suitable when dealing with moderately large surfaces, and has the advantage that it could be applied to objects of complex shape. The directions of the resultant velocities are given by the orientation of the scratches.

5. SURFACES HARDENED BY DIFFUSION TREATMENT

The boronising and chromising treatments whose abrasive wear performance was discussed in Section 2.7 offer the possibility of fruitful application where a hard surface film is acceptable, and particularly where the hardness of the abrasive is less than that conferred by these treatments. In the case of soil cultivation tools, the tolerable wear is usually much greater than 0·012 in., the typical thickness of such a hard layer. There is also the difficulty of meeting local impacts which may cause spalling of the film. As the tolerable wear exceeds the thickness of such a film, so the factor of advantage is accordingly reduced.

The most promising applications are likely to be where mating surfaces are worn by hard abrasive particles, as in unsealed bearings, gears, chains and guides, and in cases of abrasion by vegetable matter.

The latter suggestion particularly is speculative at the present stage, since no experimental information is to hand from which the relevant wear mechanism can be identified. Nevertheless, it is known that many plants secrete opaline silica, and a preparatory study was made at the N.I.A.E.[10] to produce a method of extracting such material without affecting its physical or chemical condition. A variety of silica structures (Fig. 8) were

A

B

FIG. 8.
Silicaceous residues—(*a*) Hay (× 42), (*b*) Oat grain (× 70). (By courtesy of the Journal of Agricultural Engineering Research.)

found in hay, wheat stem, oat stem, husk and grain, and these were shown to be broken up on milling. Properties of the extracted material were shown to correspond with those of opaline silica, and the material was sufficiently hard to scratch plate glass, though it still remains to establish its hardness with satisfactory precision. There is thus good reason to suppose that mechanical abrasion by plant silica may play an important part in wear against crop materials, and that treatment to render the surface harder than plant derived silica would be of great advantage.

A practical evaluation has been made in a Russian study[11] of boronised link pins and bushes in crawler tracks. Russian track links are commonly made of cast austenitic manganese steel (210 VPN), but wear on pin bores limits their service life. Bushings of various materials were used, pressed into the pin bores. Results with high carbon high chromium die-steel (700 VPN), a high carbon 5% tungsten tool steel (850 VPN), and a plain 1% carbon tool steel (770 VPN), reduced the wear on the bores by a factor of 7, 4 and 2 respectively, compared with the standard unbushed manganese steel links. Wear on the standard 0·46% carbon steel pins (650 VPN) was also reduced to about half when working in the hard steel bushings.

In a further trial, bushings and pins of 0·46% carbon steel were electrolytically boronised to approximately 2,000 VPN and compared with the standard components. Wear was thereby reduced by a factor of 17 on the pin bores and 12 on the pins. The link pins were $\frac{3}{4}$ in. diameter. Taking the tolerable total wear as $\frac{1}{32}$ in. and the case depth 0·015 in., the true factor of advantage would be about halved—that is, 8 and 6 for the bushes and pins respectively.

In brief discussions with a British firm formed recently to carry out diffusion treatments as a service to industry, some general information of practical interest was obtained.

1. Surfaces can be diffusion treated to produce films resistant to corrosion and high temperature, as well as to abrasion. Since the process is one of replacement of base material, no measurable change in physical dimensions of the part occurs, except that due to grain growth at the treatment temperature. The surface finish is a replica of the original surface, but is not necessarily reflective.

2. In chromising, the properties of the core can be restored by conventional heat tretament. The composition of the surface layer can be varied from nearly pure chromium to over 90% chromium carbide, according to the carbon content of the base metal. To achieve very high surface hardness (up to 1,800 kg/mm.^{2}), carburisation can be effected after chromising. The concentration of chromium carbide through the thickness of the diffused layer can be graduated as required. The adhesion and toughness of the surface layer is considered to be sufficient to withstand plastic flow of the underlying core material without rupture of the film or spalling. Low carbon sheet material can be chromium treated and subsequently formed, or welded to form ducting, for instance. Alternatively, thin chromised sheet metal can be applied as a cladding by welding or spot welding.

3. The current cost of the chromising treatment, taking ferrous material in strip form as an example, is 1/3 to 2/9 per pound weight of strip, according to the volume–surface area ratio, and the specification of the required film. The corresponding price range for boronising is 2/3 to 3/4 per pound weight.

4. Successful application has been made to fan blading in pulverised fuel plant, showing a wear pattern very similar to that on the hammermill fan blading in Fig. 7. Results of industrial trials lead to the conclusion that in this case it is important not only to employ a material of high hardness, but to minimise the friction coefficient of the surface.

* * *

Due to the comparatively recent introduction of the diffusion treatments referred to above, there is a general lack of published information providing evidence from specific practical trials. It is considered that this situation should be remedied and that particular attention should be given to discovering whether the advantages expected from Fig. 4, and from the allegedly superior durability of the hard surface layers with respect to impact, can be realised in practice.

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DISCUSSION

MR. G. B. H. SPEAR (Kent) asked if manufacturers were applying the information contained in Mr. Richardson's Paper.

MR. RICHARDSON said that one of his objects in preparing the Paper was to make this information available to manufacturers. Much of his data had been obtained from very fragmentary translations during the last two or three months, and he hoped that his Paper would be a means of communicating this to the industry. In fact, people with a specialist interest in wear and the metallurgical staffs of some firms were already aware of some of this work.

MR. R. A. JOSSAUME (Saffron Walden) said that he would like to mention two points. In his experience of farm machinery from Russia, he found that the long life of these machines was obtained through strength and weight. He asked if there was any relationship between speed and the amount of wear in the case of an earth-engaging tool. This was important now that ploughs and other implements were being used at higher speeds behind rubber-tyred tractors rather than track layers.

MR. RICHARDSON replied that he had dealt with speed in his written Paper. He had been concerned with work at varying speeds, and had found a different distribution of wear around an object at higher speeds. Increasing the speed from ½ mile an hour to about 5 miles an hour gave a total increase of about 17% in the wear rate over this range. Only about 6 or 7% of this increase was, he thought, due to the actual increased loading of tines due to speed, and was probably associated with the strain rate in the soil. He found that most of the wear in stony soils was caused by the stones, and if the stones were displaced at a higher rate than previously the wear rate was bound to increase. Referring to the suggested massiveness of Russian equipment, he understood from a member of a firm carrying out diffusion hardening processes that the Russians had been using diffusion hardening to increase the life of gears, in order to overcome the fact that they had not developed materials for the manufacture of gears to the same extent as we had in Europe. They still had to make the body of the gear heavy enough to take the actual loading, but they had produced a new solution to the wear problem.

MR. DOUGLAS BOMFORD (Evesham) said that Mr. Richardson had shown the relationship of hardness to resistance to wear, and he asked if it was possible for him to provide some information on the relationship between resistance to wear and cost of material, which would short-circuit the problem a little. He hoped that there were some fairly simple conclusions which could be applied by manufacturers of soil contacting parts.

MR. RICHARDSON replied that one of the main conclusions arising from the work he had been concerned with so far, and from the Russian information, was that there were many virtues in white cast iron. In the soil for which he had showed a graph giving the field results obtained at the N.I.A.E., the white cast iron was about 60% better than a good steel. However, it appeared that in other soils that value could quite easily more than double, so that if white irons could be applied by using them as inserts or by casting a martensitic iron in with a tougher iron, to form a tip, there was a fair possibility of an economic gain. However, he felt that this was an economic factor which was a matter for industry to deal with. There was certainly virtually no published information to provide guidance as to which forms of wear could most profitably be studied, and it was always difficult to find out how much it would cost to have a part made in a different material.

MR. AKHTER (National Engineering Laboratory) referred to carefully controlled laboratory experiments which had been carried out at the N.E.L. over speeds ranging,from 1×10^{-4} centimetres/second up to about 50 centimetres/second. It had been found that, over a range of the order of nearly 100, iron showed an increase in wear of only about 30%. In the case of tin and lead, very much larger changes had been observed. It was possible when ploughing in veiy dry soils that heating effects might arise, in which case speed could well be important. It had been noted that there was a possibility that pure metals of different basic structures might give different proportional relationships. For example, Dr. Rimmer and his colleagues at Imperial College had found evidence to support the theory that the cubic metals lie on a different line from that of the hexagonal metals. He had checked the ε/H graph of Khruschov, under almost identical conditions to Khruschov's, and he agreed with most of the results, except in the case of annealed steels, which did not fall on the pure metals line. Annealed steels fell on a line of different slope which did not pass through the origin. The heat-treated steels were in a very similar relationship to that shown by Khruschov.

In reply, MR. RICHARDSON said that so far as he could gather from one or two sentences in the translation some of the annealed steels had been produced by first quenching the metal and then tempering it at a temperature very near the transition temperature, so that the particular annealed structure that had been studied might not have been typical of the sort of structure normally found. With regard to the different lattice structures of the metals concerned, there was a large discrepancy for titanium, which had been included in N.I.A.E. field trials because it had a close-packed hexagonal lattice, while the other metals had some form of cubic lattice. He thought that even if the gradient of the ε/H curve varied by 20% or 30% it would not alter the present practical situation.

MR. W. J. WHITSED (Peterborough) said that Mr. Richardson had mentioned digger elevator links. The standard material for the links at present on the market was usually a straight carbon steel—a spring steel hardened and tempered to 85 tons tensile strength. He asked if Mr. Richardson thought it would be economic to increase the strength of these links by 10% or to improve them by using an alloy steel rather than a straight carbon steel.

MR. RICHARDSON said that he had always thought it would be a pity to discard a 10% advantage if this could be obtained, but from the research point of view he thought that the really exciting thing to try would be a chromising treatment. He did not know if it would be economical to do this with potato elevator links, but if the hardness could be increased up to a figure of about 1700, there should be some effect, and he would like to find out what that effect was.

DR. P. C. J. PAYNE (National College of Agricultural Engineering) asked if Mr. Richardson had done some work in correlating the coefficient of friction with wear, because this might help with regard to the economic aspects of wear. If one could obtain 10% less wear and 10% less draught, this would be all to the good.

MR. RICHARDSON replied that at the N.I.A.E. he had not been concerned with measuring friction coefficients, owing to the difficulty of doing it in the field. So far as the application of chromising to fan blades conveying pulverised fuel was concerned, he had been told that the friction coefficient appeared to be an independent variable on which the actual loading between the particles and the blade surface depended heavily. In the case of agricultural soils, this did not appear to be so, especially in stony soils. Because the stones were large compared with the dimensions of the edge, normal loading would not be substantially dependent on friction.

MR. A. PHILLIPSON (N.I.A.E., Silsoe) said that Mr. Richardson had referred to only two people working on this particular problem related to soils and agriculture. He asked if Mr. Richardson had come across other workers, and if not why did he think so little attention was being paid to the problem of wear.

MR. RICHARDSON said that, in fact, he thought that many people were working on the problem, but because they were employed by industrial organisations they were not in a position to give the results of their work to the world at large. In an American publication called " The Metals Handbook " there was much useful information on abrasion, and some of the information that had been made available in his Paper was, in fact, implied in data in the handbook. He thought that much of this information had been discovered by industry in an inexplicit way, although it had not been published formally. In addition to those people working specifically on problems of abrasion, many were using short-cut methods such as putting machines out on farms and assessing the effects from time to time or, alternatively, bringing the whole job into the laboratory for analysis.

MR. P. HEBBLETHWAITE (N.I.A.E., Silsoe) said that he wanted to pursue the analogy between the field and the laboratory. In Mr. Richardson's Paper two test machines were mentioned—namely, the K.H. 2 and the K.H. 4. He asked if Mr. Richardson could give agricultural examples where these machines provided good analogies. Was the high intensity machine a good analogy of the point of the share, and was the mouldboard an analogy for the other machine ? He noticed that there was a big difference between the K.H. 2 and 4 types of wear and of the response to pH environment. He asked for information on the effect of pH environment on wear, and whether an application of lime would necessarily alter the rate of wear on plough shares, for example.

MR. RICHARDSON replied that in checking the pH value of soils he had found no reason to suspect any effect. Khruschov's opinion appeared to be that the more slowly wearing parts might be subject to a kind of abrasion which was affected by the chemistry of the situation, due to the fact that the thickness of the layer of material being abraded was of the same order of thickness as that of the chemical film. He felt that in stony soils the mean rate of wear on the surface—that is to say the mean number of thousandths of an inch of metal worn per 100 yards—did not indicate the effective intensity of abrasion. This was because there was little effect for a given number of seconds, and then suddenly contact with a relatively large stone would remove a substantial thickness of metal. However, he had no evidence to substantiate this fully.

INSTITUTION NOTES

Birthday Honours List

Council conveys congratulations to Mr. A. Carleton Whitlock, M.I.Agr.E., a member of Council, 1959–62, on the award of an O.B.E. in the Birthday Honours List.

International Conference

The Sixth International Agricultural Engineering Conference, organised by the Commission Internationale du Génie Rural, will be held at Lausanne from September 21st – 27th, 1964. The first Bulletin on the Conference, which gives details of the provisional programme and of the submission of Papers, is obtainable from the Assistant Secretary, I.Agr.E.

Open Meetings

The first all-day open meeting in London of the 1963/64 session will be held at the Royal Society of Arts (John Adam Street, London, W.C.2) on Thursday, October 17th, 1963. Following the Presidential Address, Dr. D. P. Blight, of the National Institute of Agricultural Engineering (Scottish Station), will present a Paper on power-driven trailers—a project on which he is working at the present time. The afternoon Paper will be given by Mr. P. G. Finn-Kelcey, M.I.Agr.E., of the Electrical Research Association, on aspects of Agricultural Engineering in California, U.S.A., where he is currently engaged in research work.

Institution Ties

Institution ties will be available in September with a dark-red ground. The tie, which incorporates the design of the Presidential Badge, will continue to be available with dark-green and dark-blue grounds. Order forms may be obtained from the Assistant Secretary, I.Agr.E.

THE TECHNIQUES FOR THE FABRICATION OF TUBULAR STRUCTURES IN RELATION TO AGRICULTURAL MACHINERY

by G. B. Godfrey,* A.M.I.C.E., A.M.I. Struct. E.

SYNOPSIS

In this Paper the author gives a description of the steels employed and the processes involved in the manufacture of structural circular and rectangular hollow sections. He then gives details of their geometrical properties and compares their behaviour as structural components with the more conventional structural sections. Subsequently, he describes the methods used to design and fabricate these sections into structures, quoting the relevant British Standards where appropriate.

GRADES OF STEEL

Designers accustomed to conventional hot-rolled steel sections and plates are familiar with B.S. 15 : 1961, *Mild steel for general structural purposes*, and B.S. 968 : 1962, *High yield stress (welding quality) structural steel.* The guaranteed minimum yield stresses for the thinnest sections to these Standards are, respectively, 16 and 23 tons/sq. in., small reductions being made as the thicknesses increase.

By contrast, the Standard most often quoted for hot-rolled hollow sections in the past has been B.S. 1775 : 1951, *Steel tubes for mechanical structural and general engineering purposes.*

Among the qualities of steel at present specified are Grades 13, 16 and 20, the respective guaranteed yield stresses for which are 13·5, 16 and 20 tons/sq. in. The revised edition of this Standard, which is likely to appear later this year, will almost certainly embrace a Grade 23 steel, which is already being made and marketed.

The Grade 16 and 23 steels, which are normally made by the Open-Hearth process, are virtually identical with the steels respectively to B.S.15 and B.S. 968.

Grade 13 steel is made by the oxygen-air blown Basic Bessemer process, which produces a steel very similar in its mechanical properties to open-hearth steel.

In agricultural machinery various kinds of forgings are employed, the steel for which complies with one of the many specifications in B.S. 970 : 1955, *Wrought steels.*

TYPES OF HOLLOW SECTIONS

Structural tubes, or circular hollow sections (C.H.S.), as they are also described, are available in many thicknesses and outside diameters (o.d.), those most likely to be used for agricultural machinery being :

1. Hot finished welded (HFW) tubes not exceeding $4\frac{1}{2}$ in. o.d., produced by the continuous weld (CW) process.
2. Hot finished seamless (HFS) tubes not exceeding 18 in. o.d., produced at present by the rotary-forge or push bench process.

Square or rectangular hollow sections (R.H.S.) are made from circular sections. Seamless R.H.S. are usually made from reheated tubes, but the smallest sections, made by the C.W. process, are produced immediately after the tube has been formed, as is demonstrated in a film which describes the production and uses of R.H.S.

Ranges of tubes are included in B.S. 1775, while circular, square and rectangular hollow sections are listed in the recently-issued B.S. 4, Part 2 : 1963, *Structural steel sections—Part 2, Hot-rolled hollow sections.*

Although the smallest sections listed in the latter are $1\frac{1}{16}$ in. o.d. and 1 in. square, even smaller sections are readily available from the manufacturers. The largest R.H.S. made at present are 6×4 in. and 5 in. square, but within a few months the range will be considerably extended.

It should be noted that such sections can be supplied without or with surface protection, including galvanising.

PROPERTIES OF HOLLOW SECTIONS

When welding was introduced, designers accustomed to bolts and rivets discovered that a different technique was required for connections. In much the same way, a new approach is required when designing tubular structures, even though a hollow section is only another structural section and the basic rules of design are unchanged. In consequence, it is worth while considering the special characteristics of hollow sections and comparing them, where appropriate, with other structural media.

Geometrical Properties—Tubes

The geometrical properties of tubes required in conventional elastic analysis are :

$$\text{Cross-sectional area} = A = \frac{\pi(D^2 - d^2)}{4} \text{ (sq. in.)}$$

$$\text{Moment of inertia} = I = \frac{\pi(D^4 - d^4)}{64} \text{ (in.}^4\text{)}$$

$$\text{Polar moment of inertia} = J = \frac{\pi(D^4 - d^4)}{32} \text{ (in.}^4\text{)}$$

* Product Development Department, Stewarts & Lloyds, Ltd.

Elastic modulus of section $= Z = \frac{\pi(D^4 - d^4)}{32D}$ (in.^{3})

Radius of gyration $= r = \frac{\sqrt{(D^2 + d^2)}}{4}$ (in.)

where D = the outside diameter, and
d = the inside diameter (or bore).

The value of the radius of gyration of a solid circular bar is D/4, but for most structural tubes it is about D/3 (*e.g.*, *r* for a 3 in. o.d. × 7 s.w.g. tube is 1·00 in.).

Structures can also be designed in accordance with the Plastic Theory developed by Professor Sir John Baker, of Cambridge, although its application to agricultural machinery is probably limited. In this case, another geometrical property is required :

Plastic modulus of section $= S = \frac{(D^3 - d^3)}{6}$ (in.^{3}).

The geometrical properties quoted above, with the exception of J, are listed for all Standard tubes in B.S. 4, Part 2, and in the Manufacturers' Safe Load Tables(1).† It should be noted that J = 2I.

R.H.S.

Small R.H.S., derived from C.W. tubes, are usually rounded at the corners, the internal and external radii being equal to once and twice the wall thickness respectively. The inside of the corner of the larger R.H.S. is very slightly rounded, while the outside has a chamfer. Although the geometrical properties quoted in the documents mentioned above are strictly accurate, allowance having been made for the appropriate corner treatment, the properties can be calculated with very little inaccuracy on the assumption that the corners are square. If the external depth and breadth are, respectively D and B and the internal dimensions d and b, then :

Cross-sectional area $= A = BD - bd$ (sq. in.)

Moments of inertia, $I_{XX} = \frac{BD^3 - bd^3}{12}$ (in.^{4})

$I_{YY} = \frac{DB^3 - db^3}{12}$ (in.^{4})

Polar moment of inertia $= J = I_{XX} + I_{YY}$ (in.^{4})

Elastic moduli, $Z_{XX} = 2I_{XX}/D$ (in.^{3})

$Z_{YY} = 2I_{YY}/B$ (in.^{3})

Radii of gyration, $r_{XX} = \sqrt{(I_{XX}/A)}$ (in.)

$r_{YY} = \sqrt{(I_{YY}/A)}$ (in.)

Plastic moduli, $S_{XX} = \frac{BD^2 - bd^2}{4}$ (in.^{3})

$S_{YY} = \frac{DB^2 - db^2}{4}$ (in.^{3})

STRUCTURAL BEHAVIOUR OF HOLLOW SECTIONS

Torsion

When subjected to torque, hollow (or closed) sections show marked superiority over the open sections, such as channels or angles.

† Figures in parenthesis refer to the bibliography.

Round Bars

When a straight round steel bar is subjected to pure torsion the outside fibres are twisted longitudinally through an angle φ, so that :

$$\varphi = \frac{q}{G} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where q = the shear stress at the circumference.
G = the modulus of rigidity.
= 5,000 tons/sq. in.

The radius of the bar twists through an angle θ′, so that :

$$\theta' = \frac{L\varphi}{R} \text{ radian} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where L = the length of the bar
and R = the radius.

From (1) and (2) :

$$q = \varphi G = \frac{R\theta'}{L} \times G \quad . \quad . \quad . \quad (3)$$

For such a bar it may be shown that the torque

$$T = q\frac{J}{R}$$

Therefore, $q = \frac{TR}{J}$ (tons/sq. in.) . . (4)

It will be noted that there is an analogy between equation (4) and the common equation for bending stresses in compression and tension :

$$f_{bc} = f_{bt} = \frac{My}{I} = \frac{M}{Z}$$

Substituting from equation (3) in (4) :

$$\theta' = \frac{TL}{GJ}$$

Therefore, the angle of torsion *per unit length* of bar is

$$\theta = \frac{T}{GJ} \text{ (radian)} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

In the case of a square bar of side s, it may be useful to know that :

$$q = \frac{4{\cdot}5T}{s^3} \text{ (tons/sq. in.)}$$

$$\theta = \frac{7{\cdot}2T}{Gs^4} \text{ (radian).}$$

Hollow Sections

Using Bredt's formulas, it may be shown for a tube that the shear stress :

$$q = \frac{T}{2\pi r^2 t} \text{ (tons/sq. in.)} \quad . \quad . \quad . \quad (6)$$

where r = the mean radius ; *i.e.*, to the centre of the wall.
t = the wall thickness.

Also, the angle of twist per unit length :

$$\theta = \frac{T}{2G\pi r^3 t} \text{ (radian)} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

For rectangular hollow sections, the shear stresses in the middle of the side walls are :

$$q_d = \frac{T}{2t_d bd} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8a)$$

and $$q_b = \frac{T}{2t_b bd} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8b)$$

where d = the mean depth, between centres of wall thicknesses.

b = the mean breadth.

For such sections a symbol K, analogous to the polar moment of inertia, is used :

$$K = \frac{2b^2d^2t_bt_d}{bt_d + dt_b}$$

Using this formula, it may be shown that the angle of rotation per unit length :

$$\theta = \frac{T(bt_d + dt_b)}{2Gb^2d^2t_bt_d} \text{ (radian)} \quad . \quad . \quad (9)$$

As the wall thickness is constant in manufactured R.H.S., $t_d = t_b$ and the calculations are simplified. In the particular case of square hollow sections, further simplification occurs as d= b.

The great torsional strength of closed sections *vis-à-vis* open sections may best be demonstrated by comparing the behaviour of a complete tube with another tube identical in every respect, except that it has a longitudinal slot throughout its length, making it an open section.

If the mean radius is ten times the wall thickness (which is a reasonable figure for a structural tube), then under a given torque the shear stress in the slotted section will be *thirty* times that in the complete tube, and the angular rotation *three hundred* times as much.

As the behaviour of angles, channels and joists is similar to that of the slotted tube, it will be observed that there is everything to be gained by using hollow steel sections where great rigidity is required.

Tension

Hollow sections can be so arranged as ties that they are axially-loaded, when the full cross-sectional area can be used at allowable working stress. This is in marked contrast to an angle which is connected through one leg in which the loading is eccentric and where the section may also be reduced by bolt or rivet holes. Indeed, Clause 42a of B.S. 449 : 1959, *The use of structural steel in building*, stipulates that a reduction factor shall be applied to the outstanding legs of angles connected through one leg or to the stalks of tees connected through the table.

Compression

Compression members are described in various ways, but here they will be referred to as struts. The degree of stoutness or slenderness is denoted by the slenderness ratio which is equal to L/r, where L is the effective length and r the radius of gyration.

Very short, stout struts fail under load when the material yields, but long, slender struts collapse at much smaller stresses because they buckle into a bow shape. Struts of medium length fail by a combination of yielding and buckling.

Circular or square hollow sections, in which the material is concentrated away from the longitudinal axis of the section, possess large radii of gyration and therefore, on a weight for weight basis, they have a much smaller slenderness ratio than conventional rolled sections and can be designed to higher working stresses.

Flexure

When tubes are subjected to flexure in one plane only they are inferior to rolled steel joists. This is one of the reasons why *rectangular* hollow sections have been developed. If, however, a member may be subjected to loads of similar magnitude in two planes mutually at right-angles—say, the XX and YY axes—then a circular or square section will have advantages over a joist or channel, where there is an appreciable variation in section modulus.

Shear

Clause 23a of B.S. 449 states, *inter alia :*

" In calculating the resistance of tubes to shear, the total shear force resisted at any section shall be taken as the product of half the gross sectional area of the tube and the appropriate maximum shear stress in Table 10. Where there are holes in the section, calculations shall be made to show that the maximum shear stress given in the table is not exceeded."

It is of interest to record that the maximum shear stress varies from a value equal to twice the average stress, V/A (which gives rise to the stipulation above), for a tube with a wall infinitesimally thin to a value equal to 4/3 times the average for a solid circular bar, as shown in Fig. 1.

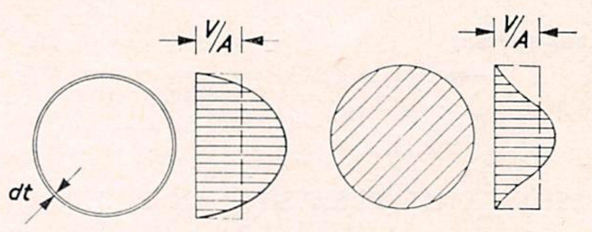

Fig. 1. Shear stresses in tubes and solid bars.

If a rigorous analysis is made for the distribution of stress due to vertical shear in a rectangular hollow section, the pattern will be as shown in Fig. 2.

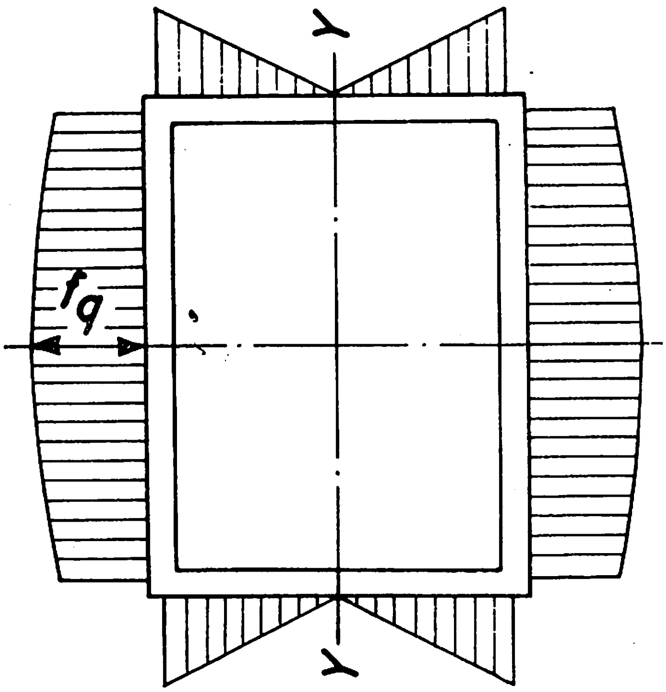

Fig. 2. Shear stresses in R.H.S.

Although Clause 23b of B.S. 449 does not specifically refer to R.H.S., it does state that the average shear stress f'_q on the gross section of the web of a channel shall not exceed the values given in Table 11. The gross section is laid down as being the depth of the section multiplied by the web thickness. Hence, if a rectangular section is assumed to be two channels welded toe-to-toe, then the average shear stress in the webs :

$$f'_q = \frac{V}{2dt}$$

where V = the vertical shear force.
d = the depth of the section.
t = the wall thickness.

In passing, it may be mentioned that rectangular sections are often made by welding two channels toe-to-toe. If they are subject largely to shear, the welds should be placed at the vertical axis YY, as in Fig. 2, where there is zero shear, rather than at the horizontal axis XX, where the maximum shear stress f_q occurs.

Having two webs, R.H.S. are not subject to excessive shear stresses. As a result, a cranked member may be made by cutting two sections on the mitre and welding up without a stiffening division plate. By contrast, if joists or channels were used, stiffening would be required at the joint.

STRUCTURAL CALCULATIONS

Of the various books available to assist in the design of steelwork, References 1 to 3 may be recommended.

In the absence of a Standard for the design of the steelwork in agricultural machinery, the allowable stresses in B.S. 449 may be used as a guide. This Standard is, of course, normally applied to static structures, whereas agricultural machinery may be said to be dynamically loaded. It is also appreciated that the full design loads on a structure are rarely applied, while those on agricultural machinery are sometimes exceeded. Nonetheless, an experienced designer can, no doubt, allow for this fact by judicious increases in the design loading.

REQUIREMENTS FOR WELDING

The relevant British Standards specifically for welding are :

B.S. 499 : 1952—
Glossary of terms (with symbols) relating to the cutting and welding of metals.

B.S. 639 : 1952—
Covered electrodes for the metal-arc welding of mild steel.

B.S. 2549 : 1954—
Covered electrodes for the metal-arc welding of medium-high tensile structural steel.

B.S. 1719 : 1951—
Classification of covered electrodes for the metal-arc welding of mild steel and of medium-high tensile steels of welding quality.

B.S. 938 : 1962—
General requirements for the metal-arc welding of structural steel tubes to B.S. 1775.

B.S. 1856 : 1952—
General requirements for the metal-arc welding of mild steel.

B.S. 2642 : 1955—
General requirements for the metal-arc welding of medium tensile weldable structural steels to B.S. 968, *Type a.*

Since a new type of steel was issued to B.S. 968 last year, B.S. 2642 has been out of date and is awaiting revision. Fortunately, for the purpose of this Paper, B.S. 938 has just been revised, but it is rather frustrating to record that all the remaining Standards are likely to be revised this year.

Section 7 of the existing B.S. 499 and Part 2 of the draft revision are important, as they give the appropriate symbols and explain how welds should be described on drawings.

B.S. 639 and B.S. 2549 are being combined into one Standard, B.S. 639, *Covered electrodes for the manual metal-arc welding of mild steel and medium-tensile steel,* and B.S. 2549 will disappear.

The revised B.S. 1719, *Classification, coding and marking of covered electrodes for metal-arc welding,* will appear in two parts, Part 1 dealing with classification and coding and Part 2, an innovation, colour identification marking.

While not wishing to dictate rules, the author can state that it is the usual practice in his firm to use electrodes with classification E 316 or E 317 for mild steel, such as Grade 16 hollow sections, and E 616 for high yield stress steel, such as Grade 23 sections.

B.S. 938, which gives a wealth of information itself, should be used in conjunction with Section G, *Welds and welding*, in B.S. 449.

THE DESIGN OF WELDS

In the early sections of this Paper information was given to enable a designer to choose the correct hollow section to carry out a certain function. In the design of a weld connecting, say, a branch to a main member, it should be borne in mind that the weld need be no stronger than the branch. Excessive welding wastes material, overheats the steelwork and induces distortion.

End-to-End Connections

When end-to-end connections are required in hollow sections, they should be made with full penetration butt welds, detailed in accordance with Appendix B of B.S. 938, and the electrodes should be appropriate to the quality of steel used. As with all other butt welds carried out under the same conditions, there is no need to design the weld. It is assumed that it is as strong as the parent metal.

Branch Connections

Clause 53b of B.S. 449 specifies the conditions under which butt welds, fillet welds and fillet-butt welds may be employed to connect a tubular branch to a tubular boom. Appendix C of B.S. 449 gives the formulas to enable the perimeter of the projected ellipse of the saddled end of the branch to be calculated for the design of fillet and fillet-butt welds. However, the brochures in Reference 1 contain all the information required to enable a designer to proportion such welds for all the Standard sizes of branches and main members and for angles of intersection between 25 and 90 degrees. The same tables can also be used for connections between tubular branches and square or rectangular hollow sections. Further information is given in Reference 4.

The author is sometimes questioned about the possibility of local buckling in the main member due to the forces applied by branches. With tubes, it has been found in practice that if the wall thickness of the branches is less than that of the main member there is a little likehliood of distortion at the joint. If unusual or freak loading is applied, the main member should be stiffened by a diaphragm welded inside, but this, of course, involves a butt joint in the main member.

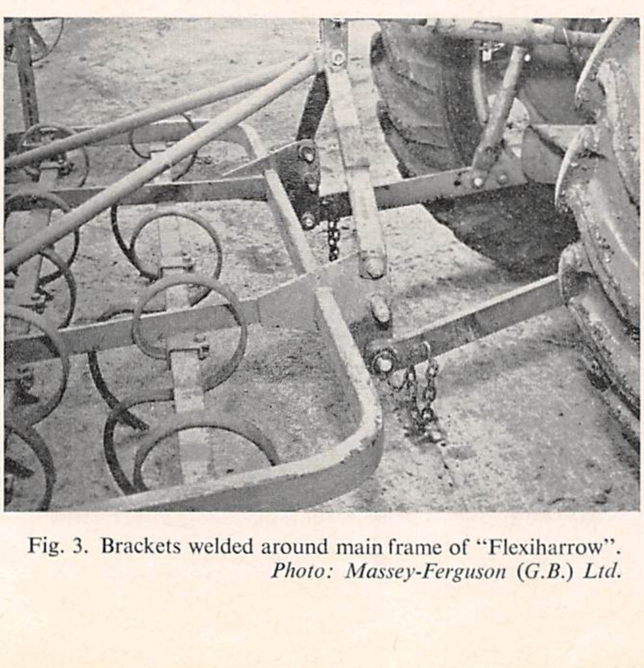

Fig. 3. Brackets welded around main frame of "Flexiharrow". *Photo: Massey-Ferguson (G.B.) Ltd.*

Cleats or brackets which can apply torque should not be welded longitudinally along a tubular main member, but across it and preferably all round it, as in Fig. 3.

Tests are in progress at Stewarts & Lloyds' Department of Research and Technical Development to try to establish a satisfactory relationship between the width of a branch and the width and thickness of the side of a square or rectangular hollow section to which it is welded. Until rules have been established, the author suggests that any branch planted on the side of such flat sections should stretch across at least two-thirds of the side.

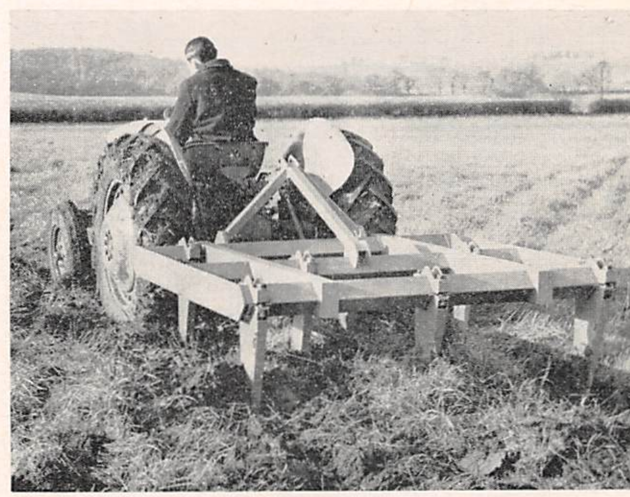

Fig 4. R.H.S. frame for "Superflow" tiller. *Photo: A. W. Andrews, Evesham.*

The three rows of square sections to which the tines are fixed in Fig. 4 embody several interesting features. By placing them so that their diagonals were vertical and horizontal, it was comparatively simple to attach the tines to them, but, in addition, they spread across the depth of the two longitudinal R.H.S. to which they were welded.

Where plates or cleats cannot be welded across the side of a main member, they should either be welded along one of the corners of the section or lapped over one of the adjacent sides.

Fillet Welds

The stress in a fillet weld must not exceed the allowable shear stress in the parent metal. For mild steel the allowable stress is 7·0 tons/sq. in., and for high tensile steel, with the appropriate electrodes, 8·5 tons/sq. in.

Table I gives the strengths of 60–90° angle fillet welds —*i.e.*, based on a throat thickness of 0·7 times the leg length. For angles between the fusion faces varying between 90 and 120°, the values in Table I must be reduced in direct proportion to the factors given in Table II.

Further information is given in B.S. 1856.

Table I
STRENGTH OF FILLET WELDS IN TONS PER LINEAL INCH FOR 60–90° ANGLES BETWEEN FUSION FACES

Fillet size in inches.	*Throat thickness in inches.*	*Safe loads in tons per lineal inch at 7·0 tons/sq. in.*	*Safe loads in tons per lineal inch at 8·5 tons/sq. in.*
3/16	0·131	0·92	1·11
1/4	0·175	1·22	1·48
5/16	0·219	1·53	1·86
3/8	0·263	1·84	2·23
7/16	0·306	2·14	2·60
1/2	0·350	2·45	2·97
5/8	0·438	3·06	3·72
3/4	0·525	3·67	4·46
7/8	0·613	4·29	5·21
1	0·700	4·90	5·95

Table II
EFFECTIVE THROAT THICKNESS OF FLAT OR CONVEX FILLET WELDS

Angle between fusion faces	60–90°	91–100°	101–106°	107–113°	114–120°
Factor by which fillet size is multiplied to give throat thickness	0·70	0·65	0·60	0·55	0·50

Lap Joints

The design of lap joints, together with appropriate tables, is adequately covered in References 3 and 5.

There are perennial discussions as to whether the lapping member should be welded on only two opposite sides, three or four sides. The author invites delegates to air their views on this subject.

Stud Welding

The stud welding of bars, bolts and studs is now commonplace in many branches of civil and mechanical engineering, but as far as the author can ascertain, it has not been applied to agricultural engineering. As it would appear to have many possible applications, delegates are again invited to comment.

SEALING HOLLOW SECTIONS

It is a fundamental concept of the design of tubular structures that all the hollow sections would be sealed to prevent internal corrosion. Where tube extremities are not sealed by being welded on to some other member, a thin disc or plate should be welded on for this purpose.

It is of interest to record that Clause 12 of B.S. 449 allows the wall thickness of sealed hollow sections to be about half that stipulated for open sections.

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DISCUSSION

MR. J. V. FOX (Bomford & Evershed, Ltd.), in opening the discussion, first congratulated Mr. Godfrey on presenting a wealth of information which would be of considerable value as a source of reference. He had been specially interested in the references Mr. Godfrey had made to the enormous strength of tubes in torsion, and in fact it seemed that tubes possessed all possible advantages. They had a high strength to weight ratio, could resist flexure in any plane, and offered more strength in tension, compression, torque or shear than any other section. In view of this, Mr. Fox asked why the use of tubular sections was not more widespread. Was there a lack of appreciation of the design factors Mr. Godfrey had referred to, or were there hidden dangers in the use of hollow sections which made them suitably only for use in the conditions of predictable stress existing in the design of farm gates, cattle pens and farm buildings ?

Mr. Fox believed that the comparatively recent introduction of rectangular hollow sections in a readily available range of standard sizes was a development which would have a far-reaching effect in the agricultural engineering industry. Rectangular hollow sections combined the strength and rigidity of tube with the ease of fitting and welding usually associated with angles, channels and flat sections. As such they offered the possibility of the development of a whole new generation of machines which were economical, sleek and sturdy. It was disappointing, although not surprising, that there was not a standard for the design of agricultural machinery steelwork ; this was almost inevitable in view of the vast range of machinery types, soil conditions and operations involved. In many cases the maximum shock loads to which components might be subjected could not be predicted with any accuracy, and even if they could be, designing up to that standard would result in machines which were so cumbersome and expensive as to be impracticable. The alternative approach of utilising safety release devices was limited, in that in most cases they would respond only to forces applied at particular points in the system and in specific directions.

The question of designed strength was of special relevance to the use of rectangular hollow sections. Although they offered greater strength than other sections, by the same token they were more difficult to repair should they become bent or broken. Many troubles of this kind could be avoided by the correct design of junctions to avoid local over-stressing, and Mr. Godfrey's remarks on the design of welds would be of great value to designers and indeed to potential buyers of machines.

One of the designer's worst problems was the possibility of fatigue failure, and Mr. Fox had been particularly glad that Mr. Godfrey had drawn attention to this point. Fatigue failure was entirely absent from short field tests and even in controlled destruction tests, and when it did occur this might be at a fraction of the designed loading. With rectangular hollow sections the main danger points seemed to be in the vicinity of welds attaching components to a main member, and in this connection too much weld seemed very often to be worse than too little. In this connection, Mr. Fox was surprised that Mr. Godfrey should have advocated welding torsion brackets all round a tubular member, since he would expect this to pre-stress the tube round its entire circumference and produce the crystalline structure which would predispose it to fatigue failure.

DR. P. C. J. PAYNE (National College of Agricultural Engineering) asked for information on the use of small fillet webs to strengthen T-joints between rectangular hollow sections.

In reply, MR. GODFREY referred to the construction of a joint using two I-section beams welded at right-angles. In such a case it was necessary to weld two stiffeners across the column at the line of the flanges of the beam, and it would also be necessary to strengthen the web of the column because it was at its weakest in shear. Using a rectangular hollow section instead, which in effect had two webs in which the shear stress was distributed, such reinforcement was not necessary. It was important when dealing with any rigid frame that the joints should be as strong as the rest of the structure, and no more. In the course of a series of tests it had been found that it was always the joint which was the place that was most heavily loaded, since it was there that there was the greatest eccentricity with respect to the load, in the case of the types of construction he was discussing. But whenever some form of stiffening had been provided in tests to destruction it was always the members adjoining the joint which failed, and no distress was to be found within the zone of the joint which had been stiffened. Mr. Godfrey and his colleagues had come to the conclusion that if rectangular hollow sections were cut on the square and welded, shear failures would be avoided.

In reply to a question regarding the difficulty of preparing the ends of tubular sections for fillet welding, Mr. Godfrey said that one of the reasons why rectangular hollow sections had been produced was to simplify the design of joints, and they could be dealt with in just the same way as for angles, channels and joists. For R.H.S. of small diameter the ends of the tube could be shaped by simple oxy-acetylene cutting machines. When dealing with larger sections, Mr. Godfrey's firm made use of paper templates and hand cutting methods, and for very large sections they used automatic cutting machines with three levers which dealt respectively with the diameters of the branch and main sections and with the angle between them.

MR. H. L. REYNOLDS (Bedford) said that it was his experience that many welding operators found the welding of junctions difficult. It was his practice when designing a structure to allow reinforcing fillets or webs to provide an additional factor of safety to cater for this.

Commenting on this, MR. GODFREY said that he felt this was a matter of experience on the part of the welders. Given practice, he was sure that they would become accustomed to the peculiarities of dealing with tubes. Answering a further question, he said that it was his impression that users of rectangular hollow sections did not always come back to the manufacturers to discuss their experiences and difficulties. His company was always very willing to help in this way.

MR. G. A. ILES (Cornwall) asked about the control of distortion in structures fabricated from rectangular hollow sections, and whether or not pre-stressing was a possibility.

MR. GODFREY replied that in his experience post-treatment was more satisfactory than pre-heat treatment.

Replying to MR. J. H. W. WILDER (Wallingford) on the problem of attaching bearings to rectangular hollow sections, MR. GODFREY said that this was one of the disadvantages of hollow sections. It was important not to put holes through tubular sections, and they should be left sealed if possible ; this could not always be arranged with standard types of bearings.

MR. H. G. PRYOR (Essex) said that he understood that rectangular hollow sections were of thinnest section at the corners, and asked if this was not a disadvantage.

MR. GODFREY replied that this was not the case—the material was of the same thickness all the way round with the smaller sections, and in the case of the larger sections there was a slight additional thickness at the corners, providing an extra degree of stiffness. The small rectangular hollow sections were made of tube of even wall thickness, and in manufacture there was no pulling of the material at the corners. The material was not expanded in any way.

MR. T. SHERWEN (Gloucestershire) asked for information on the method of manufacture of rectangular hollow sections.

In reply MR. GODFREY stated that Stewarts & Lloyds had made a film entitled " Rectangular Hollow Sections " which was available on loan and which in its introduction showed how continuous weld tubes and R.H.S. were made.

Tubes not exceeding 4½ in. o.d. were made by the continuous weld (C.W.) process while seamless tubes were made by a number of processes in sizes not exceeding 18 in. o.d.

In the C.W. process, continuous rolls of strip, the width of which was the eventual circumference of the tube, were fed into a furnace 150 ft. long, from which they emerged at a temperature of about 1,300° C. On emerging they were bent into a circular shape so that the edges were almost in contact. A jet of oxygen played on the edges to clean them and also to raise the temperature almost to molten heat. Immediately afterwards, the strip passed through a train of rolls which pressed the edges together and formed a tube.

Square hollow sections could be made by inserting appropriately-shaped rolls at the end of this roll train.

Circular tubes or square hollow sections, when once made in the manner described, were then cut to the required lengths by flying saws. Circular tubes then normally passed through " sizing " rolls which made them perfectly circular and of the exact o.d. required. When *rectangular* hollow sections were being made, these sizing rolls were replaced by appropriately-shaped rolls which deformed the tubes into the rectangular section required.

It was one of the advantages of tubes that during the various sequences of cooling, end preparation and surface treatment, they would progress through the works by rolling. Once they had been made into R.H.S., however, this was no longer possible, in consequence of which other methods of handling were required.

For sections larger than 4½ in. o.d. a different process was involved. Seamless tubes were produced from ingots or billets which were heated to about 1,300° C. and then pierced throughout almost their whole length, when they were known as " bottles."

Depending on the process involved, they were then passed over a mandril through rolls or dies from which they emerged as tubes. As these processes were slower and more involved than the C.W. process, seamless tubes were less inexpensive than C.W. tubes. Before they could be made into R.H.S., it was usually necessary to reheat seamless tubes.

While it was, no doubt, possible to form strip directly into R.H.S., as far as Mr. Godfrey was aware commercial production in Europe and the U.S.A. was based on the conversion of circular into rectangular sections.

MR. REYNOLDS said that the tensile figure for R.H.S. tubes was about 20 tons, which he regarded as rather low, and asked if there would not be more ready acceptance in agricultural engineering of tubular sections if the tensile strength could be increased to 30 or 32 tons.

MR. GODFREY referred Mr. Reynolds to the first page of his Paper where the standard grades of steel were quoted. For lightly-loaded structures or secondary members it was possible to use Grade 13 material which had a yield stress of 13·5 tons/sq. in., but he felt that Grade 16 material was the more suitable form of mild steel to use for agricultural machinery. Grade 23 material was also available when a high yield stress steel was required.

The minimum tensile strengths of the Grade 16 and Grade 23 steels were respectively 28 and 32 tons/sq. in. The *average* yield stresses and tensile strengths were considerably more than the nominal values quoted in the Standards, and in this respect they resembled conventional structural steels.

In reply to a further question by Mr. Reynolds on the crimping or flattening of the ends of tubes which Mr. Godfrey had previously demonstrated by means of lantern slides, Mr. Godfrey stated that the whole concept of tubular construction was based upon welding, bolts being used only in flanged joints for site connections. When crimping or flattening, the change of shape should be reasonably gradual, and although the ends were normally clutched between parallel faces, he saw no reason why they should not be at an angle if required.

Finally, replying to Mr. Fox's introductory remarks, Mr. Godfrey mentioned the question of fatigue. With constructions such as crane jibs, if a buckle occurred in a tubular section it was not as easy to repair as with a section, such as an angle, which had been bolted in and could easily be replaced. It might be necessary to cut out the damaged section and weld in a new one, although in some cases the buckle could be pulled out, and the member then strengthened locally. The difficulty of repairing this kind of damage was a definite disadvantage of tubular sections. So far as the practice of welding torsion brackets right round the circumference of tubes was concerned, Mr. Godfrey thought that it was important to retain the circular shape under torsion, and that where the torsional stress was high it was desirable to have reinforcement all the way round. The advantage of minimising distortion had to be balanced against the possibility of introducing local stresses due to the weld.

BOOKS RECEIVED

Electricity in Modern Farming, by FRANK E. ROWLAND. Land Books, Ltd., 1963. 60s.

The author is an acknowledged expert on agricultural electrification, and this well-illustrated book will be of immense value to all engaged in agricultural engineering and in farm mechanisation. It will also prove an excellent textbook for students. It covers all aspects of electrical engineering as applied to agriculture, from generation and distribution to the applications of electricity to farming and to horticulture. The advantages and disadvantages of various types of equipment are carefully weighed, and the bibliography will be found especially helpful. This is a timely and much-needed publication which should find a ready sale not only in this country but overseas as well.

Farm Implement Buyers' Guide, 1963. *Farm Implement and Machinery Review.* 10s.

The 200-page publication is a well-presented and comprehensive rapid reference guide to all agricultural machinery and other equipment for all sections of the farm implement and machinery trade at home and overseas.

"THE MECHANIZATION OF LIVESTOCK HUSBANDRY"

(I) "THE MECHANICAL HANDLING OF SILAGE AND CONCENTRATES IN THE FARMYARD"

by R. G. Mortimer,* B.Sc. M.S.

ALTHOUGH the terms of reference of this Paper are limited to the mechanical handling of silage and concentrates, this does not imply that there are no developments taking place in the handling of other bulky foods, such as hay and straw on the farm. In fact, we may see even greater developments with hay handling than are taking place with the two topics to be discussed this afternoon.

The development already taking place in the whole field of mechanised feeding convinces me that we are at the beginning of what might be termed "The livestock engineering era," and progress in this field could be as rapid, and as profitable, over the next 5 to 10 years as were the developments in cereal harvesting, handling and storing which took place in the last decade.

There is no doubt that, until very recently, livestock farming, apart from developments in milking machinery for dairy farms, has been largely neglected by agricultural machinery designers and manufacturers. It is also equally certain that livestock farming, with its present low profit margins, will have to increase its efficiency in the future if it is to meet not only competition from overseas, but also competition from large-scale intensive units. These may well be set up in this country with non-farming capital. The trend towards large-scale intensive units already commonplace with broilers and some pig enterprises will extend to other classes of livestock. Dairy, beef and sheep "factories" with complete automation or press-button methods are not just wild fantasies but will be the realities of the next decade. Agricultural engineers and machinery manufacturers will have an obvious part to play in these set-ups. However, you will note that the title of this Paper refers to mechanisation in the farmyard, and, therefore, I want to concentrate mainly, in the time available, on developments for the medium and small-scale farmer.

I do not intend to enter into the hay *versus* silage feeding argument, or discuss whether concentrates should, or should not, be used for stock feeding (*i.e.*, the "grass" *versus* "cake" argument). In my view, there is room for both systems of livestock production, providing both foods or combinations of them are economically used. In the past, and even at present in some cases, there has been considerable over-feeding of concentrates. Thus any mechanical handling methods used must give controls and checks on quantities used. Similarly, although grassland is the most important crop in this country as regards acreage, its potential has not yet been fully exploited. Unfortunately, even in some cases where production has been high, utilisation either as fresh material or as conserved fodder has been low. This is National Productivity Year, and whilst it may seem an anomaly to be talking about increasing output in these days of over-production, it is surely common-sense to talk about reducing wastage and getting more output that way from a given acreage of land. This simply is the theme of this Paper—namely, that since food represents 60 – 80% of livestock production costs, and labour only represents 10 – 20%, capital expenditure in machinery and buildings to enable forage to be handled with a minimum of labour is not in itself economically justified at present. This is true even when allowances are made for the increasing cost of labour and the scarcity in some areas of suitable stockmen. Thus, to be economic, capital invested in silage storage and handling must result in a considerable improvement in silage quality and a reduction in wastage. Put simply, it means that with dairy cows silage must give maintenance and at least three gallons, with the next two gallons coming mainly from the cereals, and with beef cattle it should give liveweight gains of 2½ – 3 lb. when fed with 3 – 4 lb. of a low-protein supplement.

These are the targets, and it is these factors which will influence developments in this field on the medium-sized farms in this country. The fact that with mechanical handling one man can look after 500 – 1,000 head of beef cattle is of little relevance to the farmer who is concerned with producing 200 – 500 cattle or milking around 50 cows.

So far I have said little about the actual machinery and equipment for mechanical handling. The key-piece of equipment—and I regard it as such rather than as a building—is the tower silo. A few years ago, it was necessary to explain and discuss the workings of tower silos, mechanical unloaders, auger feeders, chopper-type forage harvesters, blowers and mechanical unloading wagons or forage boxes. All of these have been used in the U.S.A. for many years, and knowledge of their operation, if not as yet their actual presence on farms, is now commonplace in this country. (The slides will illustrate their main points under U.S.A. and U.K. conditions.) Many articles describing their operation

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have appeared in the Farming Press in recent years, and several surveys of the complete range of equipment have been published.[1] The main points, as I see them, of the various pieces of equipment are as follows :

Tower Silos

These are constructed from concrete, metal or wood, and care in choosing the correct type is essential. Apart from the all-important price factor, the main considerations are :

1. Length of life associated with the resistance of material to corrosion.
2. Air tightness associated with quality of product.
3. Storage capacity in terms of tons of dry matter.
4. Ease of operating ancillary loading and unloading equipment.
5. Aesthetic considerations of setting in general farm layout ; planning authorities have differing views on this !

Modifications to improve the life of concrete stave and metal silos by the use of plastic coatings have occurred in recent years.

Seepage can be high with unwilted material and good drainage is essential, especially with concrete stave towers.

The system of unloading, either top or bottom, is dependent upon the type of silo. Top unloaders are more accessible if breakdowns occur, but are not so adaptable for re-filling in a storage, or continuous summer and winter indoor feeding system.

One top unloader can be used for two or more silos, but this involves special roof construction with monorails, etc., and the practice in some American units is to have a top unloader for each silo.

The main considerations with all the ancillary equipment are the three P's of Price, Performance and Power Requirements, coupled with simplicity of design and operation.

Forage Blowers

In addition to filling tower and trench silos, these can be used for handling chopped hay or straw. The hopper type is associated with side-delivery mechanical unloading wagons and the tray type with rear unloading trailers. Braby-Knee have produced a p.t.o.-driven stationary feeder with a moving bed for use with ordinary trailers for loading into the blower.

Silo Unloaders

The all-important feature with these is that the silage must be chopped, either by a chopper-type harvester in the field or by a chopper-blower during filling. Even cutting is essential, and whilst methods of suspension for top unloaders vary, all models perform well under British conditions, provided the dry matter of the chopped material is 20% or higher.

The bottom unloaders are used more with " haylage " or high dry matter (50%) silage.

Forage Conveyors

Evenness of feed along the manger and the ability to hanple a mixture of silage or other roughage and concentrates is essential. Whilst belts, chain conveyors and pneumatic methods can be used, the auger or helicoid-type conveyor is most popular at present.

Both open augers and tube models, with openings at set intervals, are available.

Batch feeding systems can reduce the length of conveyor needed, enabling different rations to be fed to different groups of animals, and also reduce the amount of sludge to be handled. This method should be seriously considered in future " press-button " layout designs.

Mechanical Unloading Wagons

These are multi-use machines for handling fresh and made silage from tower or trench silos, zero grazing, chopped hay, straw, roots and grain.

Some models are designed to handle farmyard manure in addition, but a problem is that farmyard manure is better rear unloaded, whilst forage blown in by harvester, unless tipped, is better front unloaded.

Tractor requirements with a complete harvesting system are high, but the use of mounted electric motors for driving mechanical unloading wagons and forage blowers can reduce this.

It should be realised that in discussing tower silos and mechanical feeding we are discussing a system of farming —not merely isolated pieces of equipment. Although because of the high capital cost of some of the items a " phasing " approach may be necessary, the aim should be to obtain as complete a system as possible. This, in turn, means that the output of grass or other forage used must be high, that utilisation must be through the right type of stock, and that management levels and stockmanship must be above average to make the system economic. I have referred to the present high capital cost, and I am hoping that we shall see some reduction in prices as manufacturing takes place in this country, rather than relying on imports from the U.S.A. and the Continent.

I do not intend to present you here with budgets based on hypothetical performance figures to determine break-even herd size or cattle numbers where tower silos and mechanical handling become economic. Most of the manufacturers of tower silos have already undertaken this exercise. Culpin[2] has produced some interesting budgets, and his conclusions are " that there is a reasonable possibility that a farmer who needs new silos and silage-making equipment for not less than a 60-cow herd could be right in deciding in favour of a tower silo mechanised feeding system." The main reason, in my view, why budgeting is a little risky at present is, firstly, that although some figures are already available from work in this country[3] we still need far more data on performances under British conditions—more input/output data, as the farm economist would say. Secondly, as inevitably happens with new methods, capital costs in some instances in this country have been unnecessarily high due to lack of knowledge of the best layouts and needs under U.K. conditions. As more experience is gained, capital costs could be less than at present. My own rule of thumb in these matters is that dairy farmers who aim to have 50 – 100-cow one or two-man units, beef producers who aim to fatten 200 – 1,000 cattle, and sheep farmers contemplating indoor housing of 400 – 1,000 ewes should seriously consider the possibilities of tower silos, and look carefully at the economics of the system on their own farms, bearing in mind the existing layout of the buildings.

At Harper Adams Agricultural College we have hap practical experience in successfully operating a 20 ft. × 40 ft. concrete stave tower silo with top unloader and auger feed over the past three years[4]. This has been used for feeding maize silage and supplement to beef cattle, but this coming season we shall be filling the tower with wilted grass silage, and next winter we hope to run trials with dairy cows, comparing performance from the tower silo with what has now almost become traditional, self-feeding from Dutch barn silos.

At present there are no satisfactory machines for mechanically unloading pit or horizontal silos. In some cases, and particularly with maize silage, it can be handled successfully with a fore-end loader or bucket, but complete mechanisation is difficult at present. In California, horizontal silos are much longer, wider and higher than in this country. Several models which work satisfactorily under such conditions in the U.S.A. have been disappointing in this country. Thus, there is scope for our machinery designers to produce suitable equipment for mechanically handling silage from Dutch barn and horizontal silos under our conditions. Possibly, something along the lines of a coal cutter with a belt conveyor to a hopper might be worth looking into, but I leave this to you as engineers to investigate.

Before considering concentrate handling, reference must be made to the new and exciting development of storage of high moisture grain in tower silos. This practice is commonplace in the U.S.A. with airtight silos, and in some instances with conventional concrete silos where suitable sealing has been undertaken. One advantage of the system is that it gives more flexibility in the use of tower silos and mechanical unloading wagons, and blowers, since they can be used for handling grain as well as silage. I expect to hear far more about this method of grain storage in the future, and high moisture barley for feeding to beef cattle and pigs, and in a few cases even dairy cows has been used in this country.

Concentrate handling presents less problems than silage, and already augers are being used for filling hoppers in herringbone parlours and conveying concentrate rations for intensive beef, pig and poultry production. As development in bulk delivery and handling of compound feeding stuffs expands, the auger will have an increasingly important part to play on livestock farms. Two possible developments in concentrate feeding already in use in the U.S.A. are the portable mill and the continuous system, or, as it is sometimes called, " the percentage system." Portable p.t.o.-driven mills and mixers are already available and operating in this country. At present their relatively high cost (about £700) seems the only barrier to prevent their widespread use on our livestock farms. Their mobility offers obvious advantages for machinery syndicates and group activity by small farmers. (Whenever I mention groups to machinery manufacturers I always get cold stares, since they naturally prefer to sell as many machines as possible. My response to this is that it is better to sell one machine to a group than no machine at all.) One problem with portable mixers is how to measure the ingredients into the machine. In the U.S.A., time clocks on conveyors bringing the minor ingredients to the mixer are used, but at present hand measuring into bags seems the best solution for our conditions. The continuous system, which is stationary, undertakes all grinding, mixing and conveying operations simultaneously and continuously from start to finish. Each ingredient is metered in at a given rate and all conveying must be done mechanically to get uniformity. The accuracy of the systems depends on the ability of the conveyors to convey uniform pre-selected amounts and on the uniformity of the materials used. Forage such as chopped hay, straw, or silage can be fed into the system in a continuous measured stream.

Thus, both silage and concentrates can now be handled mechanically on the farms of this country. There are already many instances where both systems are operating successfully. How rapidly these developments become commonplace will depend mainly on the ability of our machinery designers and manufacturers to produce equipment which fits our British conditions rather than relying on U.S.A. or Continental designs. This should be the exciting challenge for Members of this Society.

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DISCUSSION

Opening the discussion, MR. J. H. KNEE (Braby Knee, Ltd.) said that there was a great deal to be learned on the subject of the mechanisation of livestock husbandry, and that the first thing to be appreciated was that British and American types of grass were different. British grass was lush and thick and would coil itself into a rope at the slightest opportunity. Similarly, the handling of grass was very different from the handling of maize silage. He felt that the key to the whole business of handling food for livestock was the tower silo, which, in turn, necessitated the use of an efficient chopper. Chopping down to a maximum length of 1 in. was essential.

High dry matter silage or " drilage " could be defined as a silage of over 50% and under 70% moisture content, and to store such material an airtight tower silo was needed. In fact, it was not essential that the roof should be airtight, but it was absolutely necessary that the tank part of the silo should be. Mr. Knee did not feel that it was necessary to make silos which would still be in use in two generations' time, because quality of that level was very expensive, and in any case times might change. A planned life of 30 years should suffice.

It was important to ensure that the silo was evenly filled, and this called for some care in arranging for the discharge from the blower filling the silo. Uneven filling would result in difficulties subsequently with the top unloader, which would be working alternately in hard and soft cones of silage. The high prices of tower silos and equipment had been criticised, and this was inevitable while sales were restricted to small numbers. When it was possible to go into quantity production, prices could begin to come down.

Mr. Knee then raised the point that so many new ideas had depended for their successful introduction into farming on the pioneering efforts of the relatively few rich and progressive farmers who were prepared to try out such equipment. He felt that the Ministry of Agriculture experimental husbandry farms could perform this function, and that funds should be made available to permit them to do so—to carry out on-the-farm trials as soon as the manufacturer's own research had been completed satisfactorily.

MR. W. T. PRICE, Shropshire, said that Mr. Mortimer had drawn attention to the fact that only about 15% of the cost of livestock production was spent on labour. He felt that it was most important not to economise on labour to the extent that would adversely affect the 75% of costs represented by food. In this connection, he was disturbed about the wastage involved in self-feeding methods. He had two questions to ask—how was it possible to store high-moisture silage without a sealed top to the silo ? He understood that the whole point was to avoid the ingress of oxygen. Secondly, why was it necessary to use steel bands to strap concrete stave silos, in view of their high cost of maintenance ?

MR. MORTIMER said that in roofless silos a seal was achieved by means of a plastic covering. While this might involve a small amount of wastage, it was far cheaper than the cost of putting a roof on the silo. However, this practice applied to American conditions ; in Britain he felt that the normal climate made a top very desirable. Even so, he thought it worth while to have a plastic seal as well. It was possible to seal the walls of a concrete stave silo, using a plastic type of sealing material.

MR. KNEE referred to the use of iron bands on stave silos. He agreed that a reinforced concrete tower silo was preferable, but this would cost a good deal more. The use of external bands did exactly the same job at a much lower cost.

MR. REX PATERSON (Hampshire) said that Mr. Mortimer had given the impression that all silage which was not wilted was stinking muck. This he thought was misleading, as many people found it perfectly satisfactory to conserve grass outside, doing so as a pasture management practice, which made good use of surplus grass. It was possible to obtain quite appreciable wilting merely by exposure to the air, although relatively shallow depths of silage for self-feeding did not require wilting. By adopting the types of equipment of American origin for the storage of special crops such as maize or lucerne, a whole train of machinery was involved, which might not be well suited to British farming conditions.

MR. MORTIMER agreed that the types of equipment he had been discussing amounted to a complete system ; it was not just a case of a few pieces of machinery for feeding or storage of food, and the whole concept of farm management had to be adapted to that system. It was quite possible for farmers to make good silage without tower silos, and where a farmer made poor silage by using traditional methods he would not find that the installation of a tower silo automatically enabled him to make good silage.

MR. R. A. BAYETTO (British Electrical Development Association) asked for information of an engineering nature on the handling of silage.

MR. MORTIMER said he felt that there was considerable scope for the development of equipment to handle silage from trench silos, and he hoped that the agricultural engineering industry would look into this.

MR. J. U. CHARLTON (Yorkshire) said that in his experience it was not necessary to take any special measures to keep livestock back from the manger while it was being filled. While everyone recognised the value of wilted silage and the consequent elimination of silage effluent, he would like to have some information on the harvesting of wilted silage and on methods of handling it.

MR. MORTIMER said in reply that while he had shown slides of a feeding arrangement incorporating yokes, this was an experimental set-up, and the yokes were not necessary in normal practice. In fact, he doubted if even mangers were necessary, and thought that it might well be possible to place the food directly on the ground. Distribution along a manger with either an open auger, or a tube type giving slightly better distribution, was perfectly satisfactory, and the animals soon got used to it. It was only if they thought there was not enough that trouble arose. As regards the handling of wilted silage, he understood that a certain amount of work was going on at Experimental Husbandry farms. In British climatic conditions wilting could result in silage of 35 to 45% dry matter, which was a good deal wetter than was possible in American conditions.

He had shown one method of handling wilted silage. Others successfully used flail-type harvesters for chopping and re-chopping for storage in surface silos. Combined self propelled cutterbar machines with built-in conditioners could be used. In his view, a good method was to cut with a mower and then use a conditioner or do the two jobs simultaneously. In good weather 4 or 5 hours' wilting might suffice, but up to 24 hours might sometimes be necessary. It was true that conditioned grass re-absorbed moisture more quickly when it rained, which could provide problem in unsettled weather. He felt there was a good deal still to be learned about the wilting of silage.

(II) "THE DISPOSAL AND HANDLING OF LIQUID MANURE AND FARM EFFLUENT"

by WARNER K. HALL,* N.D.A., N.D.Agr.E.

INTRODUCTION

THE introduction of the recent regulations dealing with the disposal of farm effluent, along with the adoption of more intensive methods of livestock feeding and housing, has led to an urgent problem, which up to now has been in the background or "travelled down the ditch."

To cover all the aspects of this problem would be impossible, but the subject can be usefully divided into four sections :

1. *Farm Effluent and its Make-up.*
2. *Slurry Handling.*
3. *Slurry Disposal.*
4. *Manurial Values.*

FARM EFFLUENT AND ITS MAKE-UP

"Effluent" means, in the farming context, any discharge from the farm except clear rain water, and under the heading come the following products :

Waste products from livestock.
Discharge from silage production.
Dairy drainage.
Farmhouse waste.
Cheese, butter and cream production waste.
Spray chemicals.

Till recently, most of this effluent has travelled away from the farm by way of the nearest ditch, which ultimately connected with a water course. By allowing this to happen, there was no need to know the quantities of material, and only when the effluent has to be contained are the volumes realised. In this first section of the Paper, it is useful to consider this production of effluent.

In a recent survey (as yet unpublished) by Machinery Advisers of the N.A.A.S., the following figures were found for the manure produced per day by various classes of stock and collected as a liquid. These figures do not indicate the total quantity produced, as this varies with the length of time the stock might spend on bedding, etc.

Livestock	*Number of animals or birds covered*	*Amount (undiluted)/day, gals.*
Dairy cows	542	5·1
Pigs (fattening)	6,168	1·6
Poultry (per 100 head)	27,800	6·2

The figure in some cases is only a fraction of the total, as indicated by figures of water consumption from a 43-cow unit/day.

Cow consumption	120 galls.
Washing parlour	160 ,,
Washing pipeline..	30 ,,
Washing, collecting and dispersal yards	260 ,,
	570 galls.

This is 13·25 galls. per cow/day.

The total amount of effluent from a unit can be found from a combination of many facts. When constructing a storage area, factors such as frequency of emptying and methods of emptying must be taken into account. The following figures can be a guide to effluent output from varying stock units :

A tank 30 × 10 × 10 ft. will hold 19,000 gallons. This can be expressed as :

1,000 cow days	or	19 gals./cow/day
7,500 pig days—meal fed	or	$2\frac{1}{2}$ gals./pig/day
6,000 pig days—whey fed	or	3 gals./pig/day
240,000 hen days	or	8 gals./100 birds/day

These figures are only a guide and can vary from farm to farm.

SLURRY HANDLING

There are two ways of handling the slurry :

1. As a semi-solid.
2. As a liquid.

1. Handling as a Semi-Solid

In many cases of intensive livestock production, housing is under cover and the material produced is in a solid state.

By constructing a collecting point where all manure is scraped up a ramp or into a pit containing a spreader, handling is as for farmyard manure.

In many cases the difference between handling the manure as a solid or as a liquid might be changed by adding extra roof area.

In all cases, however, the liquids from the farm buildings, which are classified as "effluent," will be handled as a liquid, or if straw is available a compost could be produced by pumping out on to the straw.

Another recent approach to this problem is the use of a centrifuge, which leaves the material in an easily-handled condition. This is being considered where intensive units are situated in a built-up area, the liquid being pumped into the sewage system.

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2. Handling as a Liquid

This alternative is more suitable to most farms, as all the effluent can be treated and handled as a liquid.

An important point to note is that with all methods of disposal, including pumping through a pipeline, the liquid should be kept to a reasonable dilution.

All rainfall should be kept from the tank unless required for dilution at some time, in which case simple by-pass valving can produce the desired results. Always remember, 1 in. of rain falling on 1,000 sq. ft. gives 500 gallons, so it is important to redirect all rainfall from the farm. (This can go straight into the ditch.)

The dilution of the material depends to a large extent on the system of emptying.

With a tanker system the rate of work is often no more than 1,000 gals./hr., compared with 6,000 gals./hr. with the pipeline. It is important, therefore, with a tanker to reduce the liquid content. Power washing of yards for cleaning uses 3,600 gals./hr., which could embarrass a tanker system. A more suitable alternative would be the use of a tractor scraper.

With all methods of emptying it is important to combine them with efficient methods of filling the tank ; *i.e.*, whereas savings in labour can result in the disposal, it is possible to use too much labour in yard cleaning, etc.

It has been found that using a mains hose for cleaning is no quicker than using a bucket.

Mechanical cleaning using a tractor scraper must be well organised and the equipment must be to hand, as inefficient systems of use may make the operation uneconomic. With a well-organised system, rate of work can be 0·8 min./100 sq. ft., with corresponding figures for power hose of 0·45 min./100 sq. ft. With large yards, however, the use of a power hose becomes difficult and the tractor scraper is better.

When moving effluent through drains, they should preferably be of the open pattern with a minimum of 9 in. diameter, with a slope of 1 in 40 – 1 in 70. All collecting points in a yard should be no smaller than 4 × 4 ft., with a grating over. This enables the straw and long material to be removed from the slurry and cuts out the cost of expensive equipment to chop this material.

Storage Arrangements

The most popular construction of container is in reinforced concrete block, which is rendered to prevent leakage. When constructing a tank, it is worth making it square in section—*i.e.*, 10 × 10 ft.—so that, if required, agitation paddles can be fitted later. Where paddles are fitted, it is thought worthwhile to round the bottom of the tank to make sure all the contents are moved about. Another alternative, where the site is available, is the construction of an earth tank. This is sometimes described as a " lagoon," but differs from the American lagoon, in that in this country, with our weather conditions, very little bacterial breakdown occurs and the lagoon becomes a large storage tank. A polythene lining can be added to the tank at a relatively small cost if seepage is a problem.

EFFLUENT DISPOSAL

Distribution from the storage area can be by one of these main methods :

(*a*) *Tanker or unit loads.*
(*b*) *Distribution through a pipeline.*
(*c*) *Combinations of* (*a*) *and* (*b*).

(*a*) Tanker Systems

With this system a tank holding from 400 – 600 gallons is filled either by evacuating the tank by a vacuum pump (p.t.o.-driven) or by some pumping system usually employing a diaphragm pump. They should all have a filling rate of at least 50 g.p.m.

The tanker system has the following advantages :

(1) Low cost system.
(2) It can reach outlying points on the farm without increase in equipment cost.
(3) It is a piece of equipment which can be readily shared or owned by a syndicate.
(4) There is very little maintenance.

There are, however, the following possible disadvantages :

(1) Unless a large storage area is provided, times of emptying might coincide with periods of wet weather when the loadings cannot be carried by the soil.
(2) Labour requirement is higher compared with some of the pipeline systems.
(3) A simple tanker cannot be used readily for yard cleaning.
(4) High dilution rates resulting from some cleaning methods do not suit the tanker.

(*b*) Distribution through a pipeline

Although at one time this system was considered expensive, it has been possible to reduce various items in the equipment, such as agitator and cutter mixer pumps, and use the pump for agitation by recirculation with the cutters on the pump. It is important, however, not to rely on the pump cutter to deal with all material, and prevention of blockage is a lot more satisfactory than having to stop and clear the system when in operation.

The pipeline system has the following advantages :

i. Labour requirement can be low, but only if tied to an efficient cleaning and tank filling system.
ii. A high dilution rate can be tolerated as most systems work around 6,000 gals./hr.
iii. The system can be used cheaply for clear water irrigation by obtaining a different impeller in the pump and different rain-guns.
iv. It can be used for yard cleaning, etc.
v. The loadings on the land in adverse weather conditions are virtually nil.

The system does, however, have the possible disadvantages :

i. The equipment cost can be high.

ii. The soil might be unsuitable to take large quantities of water.

iii. In windy conditions and on sloping land the distribution can be uneven.

iv. The smell in populated areas can be a factor. Tankers drop their load quickly with a small air contact and therefore can be less of a nuisance.

v. Frosty weather can bring the whole system to a standstill.

With the pipeline system a supply of clear water is an advantage, so that all equipment can be cleaned at the end of pumping. On some farms the value of this clear water lies in the ability to clean the herbage in the field to reduce the unpalatability which can result from liquid manure application.

Combinations of (*a*) **and** (*b*)

Recently introduced, this equipment consists of a larger tanker (700 gallons), which is fitted with vacuum filling. Disposal is by an irrigation pump mounted on the tanker, and then through a pipeline. The disadvantage of the tanker travelling over the land in the winter does not apply as long as a hard road is available, and the disadvantage of the piped systems' expense of length of pipeline to cover the whole farm does not apply.

The labour requirement and cost of operation of the various systems are difficult to obtain, and do of course, vary widely from farm to farm.

From an Unpublished Survey

With a tanker system the total labour requirement for filling the tank (cleaning yards, etc.) and emptying ranged from 40 – 294 man min./1,000 gallons, with an average of 135 man min./1,000 gallons.

In the pipeline system the total requirement ranged from 5·7 – 67·3 man min./1,000 gallons, with the pumping requiring 7·1 man min./1,000 gallons.

Although the cost of the irrigation equipment can be high, the labour requirement can be considerably reduced.

Taking all these factors into account, the following figures can be obtained :

Cost of Operation/Hour

Tanker system ..	£1 6s. 6d. per hr.	or 1,000 gals.
Pipeline	£1 8s. 6d. per hr.	or 6,000 gals.
Contractor's tanker	£1 15s. 0d. per hr.	or 1,000 plus gals.

If a contractor could get a whole day's work in one area, the above figures could well be obtained and compared favourably with the other farm methods.

MANURIAL VALUES

Many farmers do not consider the effluent a valuable asset to the farms and treat the problem as one of disposal. It is a fact that when most of the effluent needs to be applied in the winter months, the soil does not require it, nor is there any crop growth.

Taking into account the loss of efficiency of the nutrients, the following figures were obtained from the survey :

Estimated value of undiluted manures per 1,000 gallons :

Cow Slurry ..	14/-
Pig Slurry	26/-
Poultry Slurry ..	37/-

Field results generally agreed with these figures.

The manurial value can therefore offset the cost of disposal in some cases.

The whole problem is vast and complex, but this Paper has covered most of the major problems and can give a guide to answers to the problem on most farms.

DISCUSSION

MR. D. E. WILLOWS (N.A.A.S. Bedford) opened the discussion by saying that he had noted Mr. Hall's remarks to the effect that the lagoon system probably was not applicable to conditions in this country at present. He felt that this might be true, especially after the kind of winter that had just been experienced, but that lagoons should not be dismissed altogether. In a lagoon, which provided a predominantly anaerobic method of digesting organic materials, one had a large surface area and relatively shallow depth of water, into which water and manure were pumped and allowed to digest over a long period. Admittedly, the rate of digestion depended on the temperature, among other things, but the fact that there were cold winters did not mean that the process stopped for ever. Its main advantage was that it provided the farmer with a large reservoir area which need not be pumped out at times when it was inconvenient ; against it could be levelled the fact that one lost some of the nutrients in the material.

Mr. Hall had provided some data on the amount of material one would expect to handle for different classes of livestock, and in his Paper he had stressed the importance of controlling the dilution rate. Mr. Willows felt that this needed further emphasis. If the concentration was too high, there were the problems of de-watering and it was difficult to get the manure to collect in a storage tank. On the other hand, too low a concentration either required a very large storage tank or very frequent emptying, either of which was costly. In the investigation referred to in the Paper it had become fairly clear that the collection of manure from pigs and poultry could be made labour-saving, but this was by no means the case with dairy cattle. There were a number of important points concerning the disposal of cow manure which should be made. The time spent in cleaning down a concrete yard was closely related to its area, and hence it was important to restrict the area open to the cattle to that appropriate to the size of herd in question. To keep only 25 cows on an area big enough for 50 was simply to intensify the problem, and this was not always realised.

Turning to his next point, Mr. Willows said that oıdinary irrigation.

slatted floors were now being treated with a certain amount of reservation, because they solved some of the problems—such as the provision of bedding—but left others in their train. Slats alone did not seem to be the whole answer, but it seemed quite possible that slats in conjunction with cow cubicles might offer the possibility of getting the same kind of results with cows that were already being obtained with pigs and poultry.

MR. P. O. WAKEFORD (Sussex) said that the West of Scotland College of Agriculture had been experimenting at Auchincruive with slatted floors between cow cubicles, and had found them to work very well during the last winter. They provided very comfortable conditions for the cows, and the sludge drained down a slope of 1 in 80 or 100 to a sump. It was important that the sump should be big enough to enable the tanker to be filled at maximum rate, as the inflow of sludge down a slope as gradual as this was very slow.

MR. C. V. BRÚTEY (National Farmers' Union) said that the N.F.U. had been investigating the problem of manure disposal, and particularly the legal and economic aspects of it. They had not so far found an answer to the problems of the farmer on heavy land which tended to waterlog, or in areas of high rainfall. It appeared that the only satisfactory alternative to putting the effluent into the sewers was organic irrigation, and this was not being well received in these areas. Experts seemed to be divided between those who thought the amount of extra moisture put on the land by organic irrigation was so small in proportion to what was already there that it was insignificant, and those who were convinced that it was very significant. He would welcome comment on this point.

MR. HALL replied that this was one of the most controversial points relating to organic irrigation. In his opinion, it depended entirely on the type of soil in question. There were some soils which behaved unsatisfactorily under raingun irrigation in the summer, and clearly these would also be likely to be unsuitable for organic irrigation in the winter. The soil chemists he had approached appeared to feel that there was not yet sufficient experience of organic irrigation to be able to draw any definite conclusions on this point. He would like to ask if it was really necessary to make the manure into a liquid. Could one not reduce the amount of water to the minimum and handle the manure as a solid ? The urine, and water from the dairy, could go down the town sewers, because it was the solids—the cow dung—which had such a high oxygen demand that it did not easily break down on a sewage farm. In areas where the land could stand up to organic irrigation one could use cubicles with slats between them ; otherwise the dung would have to be pushed out in a fairly solid state and stacked until it was possible to distribute it on the land in the normal way. It was important to keep one's thinking flexible, and be prepared to handle the manure either as a liquid or as a solid.

MR. W. T. PRICE (Shropshire) said that he could imagine that the smell in the countryside would be terrible if all farmers adopted organic irrigation. In his view, a workable system was to go over the loafing area—whether in conjunction with a bedded area or with cubicles was immaterial—two or three times a week with a scraper shovel. One would then have a material which could be handled easily and with a comparatively small outlay on equipment. He also referred to the problem presented by silage effluent.

In reply, MR. HALL said that, in his opinion, the smell of manure disposed of by organic irrigation was no worse than that of farmyard manure. He understood that an American firm had developed a manure deoderant which could be applied at the rate of about 2 quarts per 100,000 gallons of liquid manure, which was quite cheap to apply if it were really necessary. Regarding silage effluent, while it was true that this had been a serious problem up to three or four years ago, it was his opinion that it was no longer so. He had seen very little silage effluent in the last few years. In answer to a question on the possibility of producing methane by fermenting excreta under controlled conditions, Mr. Hall said that, while it was theoretically possible to obtain methane in this way, and the calorific value of the methane obtained from the excreta of four cows in the course of a year was equivalent to about 130 gallons of petrol, this required a very expensive plant and was not a commercial proposition for all-the-year-round consumption.

MR. C. CULPIN (N.A.A.S. Silsoe) agreed that the process notdid at the present time seem to be commercially practicable.

MR. I. B. WARBOYS (University College of Wales, Aberystwyth) referred to the experience of his College with dairy cows. Slats were installed in the feeding area, and it was found necessary to remove the slats once a year only for cleaning out. The concrete surface in covered collecting yards had been found to present a hazard to the cows when it was wet, and he asked if there were alternatives to concrete which could be used for this purpose.

MR. HALL said that where power hoses were used for yard cleaning there might be the problem of wet and slippery surfaces, but this did not arise if a scraper method was adopted. He knew of no alternative which was better than concrete. In answer to another question regarding the after-effects of organic irrigation on grassland, and whether or not the pasture became rank and unpalatable to grazing livestock, Mr. Hall said that application of cow manure to land subsequently to be grazed by cows could lead to unpalatibility. Usually it was possible to apply organic irrigation in rotation so that one did not graze again straight after an application. He had heard it said that pumping clear water through the system for a period after the manure application was beneficial. Application of manure from pigs or poultry did not seem to have an adverse effect on the grazing of the cows. One farmer he knew grazed his sheep rotationally, and in his system the lambs grazed first, followed by the ewes, followed by an application of pig manure. This appeared to be very successful.

MR. G. C. MOUAT (Essex Institute of Agriculture, Writtle) asked how much of the equipment required for organic irrigation was common with that used for

MR. HALL replied that pumps fitted with choppers for organic irrigation could also be used for clear water, and the pipelines were exactly the same. Some clear water pumps could be fitted with choppers to make them suitable for organic irrigation. However, he thought that rain guns should not normally be used for clear water application, as better results could be obtained by putting the water on at a lower rate through sprinklers.

MR. W. T. A. RUNDLE (Hampshire) said that in organic irrigation there was normally a considerable amount of solids to be pumped, for which an open vane type of pump was most suitable. Since the efficiency of this type of pump was rather low, closed shrouded types of impeller were usually fitted for clear water pumping and gave a much higher efficiency. Because the latter type of pump was subject to blockage by the solids, in practice the manufacturer had to decide in which direction he would compromise. Alternative types of impeller for the two different tasks were preferable. Referring to earlier remarks suggesting that collection of the urine was not important, Mr. Rundle emphasised that two-thirds of the nitrogen was to be found in the urine. While rain water could certainly be excluded from the manure, the urine should not be lost if it was intended to retain the maximum fertilising value.

OBITUARIES

The Council records with deep regret the death of the following members :

Mr. A. C. Hutt

Mr. Arthur Cyril Hutt, A.M.I.Mech.E., M.I.Agr.E., who died on April 21st, 1963, at the age of 78, was a founder member of the Institution. He served in the Royal Navy in both world wars with the rank of Lt.-Commander (E.).

His first connection with agriculture was his work with the London and Counties Coke Association in 1935, where he commenced his work on Crop Drying. He maintained his close connection with agriculture during the Second World War, particularly in his work regarding the preparation of animal feeding stuffs from salvaged material. His publication " Combine Harvesting and Grain Drying " is a well-balanced and informative work on harvesting and harvesting equipment.

In 1948 he was appointed Senior Technical Adviser to the Coke Department of the Gas Council, where he continued until his retirement in 1956. He was still active in his retirement, and was able to make a long visit to Uganda, where his son Michael is Professor of Pathology at Makerere University College, East Africa.

Mr. Hutt was Honorary Treasurer of the Institution from 1947–51, contributing much to the establishment of the Institution on a sound financial basis.

Mr. P. W. Lester

Mr. Percy Wilfred Lester, of Pitchill, near Evesham, died suddenly on May 15th. He was especially active in the work of the West Midlands branch, of which he was the Honorary Treasurer and a Past Chairman.

Mr. Lester, who was 61, had been on the staff of Bomford Brothers, Ltd., for forty years, and for the past nine years had been the company's Managing Director. It was his responsibility to co-ordinate the development, production, sales and maintenance of the machines manufactured by his company—a task which enabled him to put to good use his sound practical engineering experience.

That experience Mr. Lester was at all times ready to share with others. The Institution benefited from it in many ways, and particularly by the Paper entitled " Jig Design for Batch Production of Agricultural Machinery in the Small Works," which he presented in 1958.

Mr. A. W. Riddolls

Mr. Alec Wilson Riddolls, B.Sc., B.E., A.M.I.Mech.E., M.I.Agr.E., Reader in Agricultural Engineering and a member of the professorial board at Lincoln College, University of New Zealand, died suddenly in Christchurch on May 18th, aged 55. Born in Colne, Lancashire, he emigrated to New Zealand at the age of about 12.

Appointed to the newly-created full-time post of Lecturer in Agricultural Engineering at Lincoln College in 1944, Mr. Riddolls was responsible for the development of the whole programme of teaching and research in agricultural engineering at the College, which for a number of years entered students for the National Diploma in Agricultural Engineering.

In addition to publishing a number of technical Papers, Mr. Riddolls wrote a textbook, " Farm Engineering." He served on Committees of the New Zealand Standards Institute, working on draft standards for materials and equipment for agriculture.

In 1953 he was appointed Institution representative in New Zealand—an undertaking to which he devoted himself with great energy and enthusiasm.

SPEECHES AT THE ANNUAL DINNER OF THE INSTITUTION

25th April 1963

MR. J. H. PITCHFORD, Immediate Past President, Institution of Mechanical Engineers, proposing the toast of "The Institution of Agricultural Engineers," emphasised to the 130 members and guests gathered at the Cafe Royal the strength of his ties with agricultural engineering. Throughout the whole of his working life he had been concerned with research and development in the field of the internal combustion engine, and the growing importance of this prime mover in agriculture had brought him into contact with the people in many countries concerned with agricultural engineering and its very particular and special problems with relation to the power unit. Moreover, he was delighted to say that his son was happily settled in agricultural engineering.

While there was still some latitude for improvement in some of the equipment he had examined, no longer did people speak, as they once did, of "a bit of real agricultural engineering" when describing something particularly offensive to the mechanical purist, and it was the growth of the Institution, with its clear and well-expressed objectives, which had done as much as anything towards changing the climate in this way. The Year Book was a model of what such a publication should be.

He was very conscious of the common ground between the two Institutions, and it was his intention to urge joint meetings in the future, in particular between the I.Mech.E. Mechanical Handling and Hydraulics Groups and the I.Agr.E. There should be no opportunity let slip of consulting together upon matters of common interest, and he extended a cordial invitation to I.Agr.E. members to join the subsequent Earth Moving Equipment Symposium and Hydraulics Group Convention. It was with particular pleasure that he had learned during his term of office of the Award of the I.Mech.E. Crompton Lanchester Prize to Mr. David Manby, A.M.I.Agr.E., for his Paper on the "Measurement of Tractor Performance," presented at the Symposium on Agricultural Tractors.

He looked forward to the day when it would prove possible for the I.Agr.E. to take its seat on the recently formed Engineering Institutions' Joint Council. It was in this connection that he noted with satisfaction one of the I.Agr.E. avowed objectives—"The promotion of higher educational standards in agricultural engineering." He knew that he would not be misunderstood when he said that, if the senior professional engineering institutions of this country were to continue to fulfill their proper roles, both with respect to their own membership and to British engineering as a whole, they must as a matter of first priority maintain, and indeed raise, the standards of their professional qualification. It was well recognised amongst those bodies who were already members of the E.I.J.C. that their respective qualifying requirements varied considerably, but it was important that all realised that there should be a continuous movement upwards. The common goal must be a high standard in all branches of engineering throughout the country to the great benefit of British engineers and British engineering in the eyes of a watching and observant world.

"Your Institution represents one of this country's most vigorous and successful manufacturing engineering industries, and it gives me the greatest pleasure to ask you all to drink with me the toast of the Institution of Agricultural Engineers, coupled with the name of its President."

Responding to the toast, the PRESIDENT said that to receive the commendation of an engineer who 24 hours ago completed a distinguished term as President of the Institution of Mechanical Engineers was something which the Institution of Agricultural Engineers deeply appreciated in this its Silver Jubilee year.

He was deeply sensible of the honour bestowed upon him by electing him to the presidential chair. He equally esteemed this acknowledgment by the Institution to the contribution made to the development of agricultural engineering by the trade and technical Press. An interesting precedent here was that for several years he had been privileged to work for the distinguished editor of an old-established technical journal who was elected President to the Institution of Mechanical Engineers in 1930—the year in which that Institution was granted its Royal Charter.

"It may not be as widely known as it should be," said the President, "that this Institution is now 25 years old. Perhaps there have been times in this quarter-of-a-century when we have not banged the big drum as much as we should have done. The Institution has never lost sight of that small band of engineers who in 1938 decided that there was a place for an organisation which could emphasise the importance of the professional status of those engaged in agricultural engineering. Our great concern, however, must be with the present and the future." He would say boldly and with deep conviction that agricultural engineering—incorporating as it did a "peculiar mixture" of several technologies—had to-day a greater contribution to make to the peace and well-being of the world than ever before, for it was the task of agricultural engineers in this increasingly scientific age to provide mankind's basic requirement—food; otherwise civilisation could not progress. Thus it was of tremendous importance that the agricultural engineers of to-day and tomorrow should aspire to high standards of training and qualification. The Institution was extremely proud of the prodigous effort it had exerted in co-operation with the Agricultural Engineers' Association and the Agricultural Machinery and Tractor Dealers' Association to secure the establishment of the National College of Agricultural Engineering. He was confident that the strong liaison between the College and the Institution would be productive of great good.

The Institution was very conscious of its responsibility as a body corporate. With eight active branches in this country and members in many countries overseas, it was under no illusion about the need to strive for high qualification for membership. Council was determined that membership of the I.Agr.E. should become more and more recognised throughout the world as a hallmark of the highest compteence.

He wished to express his gratitude that in the past few months the Agricultural Engineers' Association had done yeoman service by attracting the special attention of its member firms to the objectives of the Institution. Assistance of that kind was bound to be of great value in a serious attempt to enhance still further agiicultural engineering prestige. Notable also were the many ways in which the distributors weie striving to achieve higher standards of technical efficiency in their section of the industry.

The endeavours of the Institution could never have got to their present stage without the enthusiasm and devoted service of the Secretary. To Mr. Ronald Slade and the small team which he directed the Institution expressed its gratitude ; the debt of gratitude owed to him was enormous.

Words of Archimedes gave MR. PRIEST his close : " Give me a firm spot on which to stand, and I will move the earth." Mr. Priest believed that, at the end of its first 25 years, the Institution had a firm spot on which to stand. " As we step forward, we are dedicated to the task of helping agiicultural engineers to move the whole earth ; and to move it in such a way that it will bring forth its fruits more abundantly for the service and enjoyment of all mankind. We hope that through these efforts we shall deserve a place in the Engineering Institutions' Joint Council."

DR. P. C. J. PAYNE, Principal of the National College of Agricultural Engineering, proposed the toast to " The Guests." He was delighted at being invited on the occasion of the first Annual Dinner since the College had had physical as well as notional existence, to propose a toast to the guests and to be able to thank those who had done their part in getting the College established.

Dr. Payne recalled Past President Mr. Nolan's words that the Annual Dinner was the one occasion when the Institution had an opportunity of paying tribute to a small proportion of the friends of the Institution who had done so much for it. He welcomed the representatives of affiliated organisations who gave material financial support. He was glad to see that the Agricultural Engineers' Association and the Agricultural Machinery and Tractor Dealers' Association were so well represented. It was notable that in the past most difficult year for exports the industry had achieved about an 8% rise in its exports. He had reason to know Air Vice-Marshal Hopps better than some because he was being instrumental in giving the College £50,000 worth of machinery. Mr. Ben Burgess changed hats very frequently ; tonight he was wearing an I.Agr.E. hat, and next week he would wear a hat labelled " Education for Distributors." He also welcomed Mr. Southcombe, who was the first to sign the Visitors' Book at the National College.

Dr. Payne paid tribute to the Board of Governors and the Principal of the Essex Institute of Agriculture, and expressed his pleasure in seeing Alderman Rose and Councillor Tabor, Chairman and Immediate Past Chairman of the Board, among the gathering. The College had rendered outstanding service to the Institution over the past 9 or 10 years. It had both provided training for the N.D.Agr.E. and made available examination facilities. He should, perhaps, add that in paying tribute to Chairmen of College Boards of Governors he was speaking from personal experience and was delighted that his own Chairman, Sir Gilbert Fleming, again numbered amongst the distinguished guests.

AIR VICE-MARSHAL F. L. HOPPS, Secretary and Chief Executive, Agricultural Engineers' Association, responding, said that the guests were most grateful for the kind invitation and greatly appreciated the hospitality.

The response was to have been made by Mr. Tom Cummings (President, A.E.A.), who was delayed in Scotland, and he suspected he had been given the honour of responding to the toast of the guests primarily because he was the only one possessing a copy of Mr. Cummings' notes !

The Annual Dinners of the Institution were always outstandingly enjoyable occasions, but, more than this, they were also milestones on the road of progress and achievement. In a commercial company, achievement was measured by the balance sheet, but in an Institution such as the I.Agr.E., accumulation of knowledge and the encouragement and education of agricultural engineers formed the credit side of the balance sheet. Members of the Institution had given and were giving invaluable assistance to one of Britain's greatest industries.

Mr. Cummings was to have said, and he said on his own behalf, that he was pleased and honoured at being asked to speak—pleased because he had anticipated an enjoyable occasion and welcomed the opportunity to express his gratitude, and honoured because he was from the " other " body where it was customary to speak of the Institution in hushed tones, and to refer to it cryptically as the " learned " body, realising that they were only the producers of machines which work!

Friendly co-operation between all branches of the industry was its great strength and it contributed to making it what it is to-day—the largest exporter of agricultural machinery in the world. This was not an accident. It was the direct outcome of liaison between the manufacturers, engineers and the farmers. On behalf of all present, he wished to repeat their appreciation of the Institution's value to the industry.

ELECTIONS

Approved by Council at their Meeting on the 28th March, 1963

MEMBER		Barker, M. G.	Cambridgeshire
		Cullen, M. H.	Midlothian
ASSOCIATE MEMBERS		Angier, T. D.	Warwickshire
		Brooke, J. W.	Yorkshire
		Dilley, C.	Leicestershire
		Evans, D. C. P.	Berkshire
		Jackson, K. G.	Yorkshire
		Pullan, Thomas	Yorkshire
		Smith, D. W.	Bedfordshire
		Swinson, W. C.	London
	Overseas ..	Adjari, Aliasghar	Iran
		Keech, M. A.	Southern Rhodesia
		U. San Shwe Mya	Burma
ASSOCIATES		Britt, A. L...	Cornwall
		Copping, G. S.	Buckinghamshire
		Miller, K. H.	Suffolk
		Shaw, D. C.	Warwickshire
	Overseas ..	Bradford, J. S.	Kenya
		Collin, D. C.	Uganda
GRADUATES		Davies, A. W. B.	Wiltshire
		Laing, A. S.	Yorkshire
		Lavy, M.	Yorkshire
		Reynolds, J. E. V.	Buckinghamshire
		Walters, A. J.	Devonshire
	Overseas ..	Keese, P. H.	Kenya

TRANSFERS

FROM ASSOCIATE MEMBER TO MEMBER ..	Hollis, J. C.	Shropshire
FROM GRADUATE TO ASSOCIATE MEMBER	Howland, J. L.	Warwickshire
	Talamo, J. D. C.	Bedfordshire
FROM GRADUATE TO ASSOCIATE	Townshend, D. C. R. ..	Essex
FROM STUDENT TO GRADUATE	Wakeham, G. F. D... ..	Suffolk

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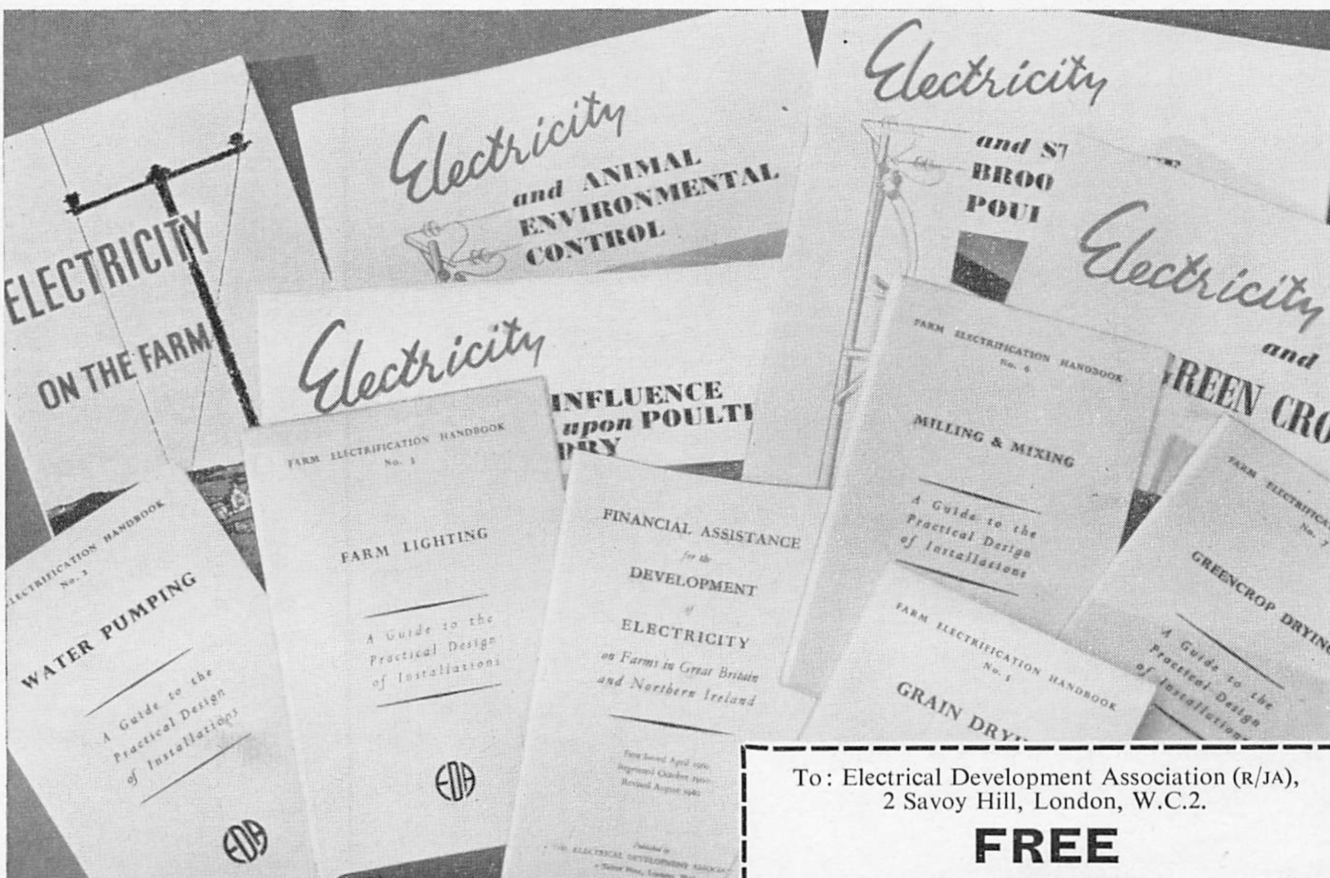

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IN THIS ISSUE

Because of the rearrangement of London Open Meetings, the Journal will in future be published in February, May, August, and November each year.

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