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EDITORIAL

It is no doubt part of the rheologist's work to try to provide a plausible explanation of non-Newtonian viscosity and non-Hookean elasticity in terms of molecular configurations. It is, however, equally part of his work to establish rheological equations of state connecting the stress, strain and flow tensors of a real material under given conditions of experiment. We must know precisely *how* a system behaves before we can speculate about *why* it so behaves. Usually the equation of state must be derived from observations made on the material as received: to dilute it or to heat it means all too often to destroy permanently its rheologically interesting and valuable properties, and the relevant equation of state cannot be predicted from the behaviour of the highly diluted system.

Prof. Reiner's contribution on the use of mechanical models in rheology seems much to the point. As he remarks, the use of arrays of springs, dashpots and friction elements may be, and often is, helpful in formulating an equation connecting stress, strain and other variables; but once this has been done, the model has served its purpose. It is fatally easy to assume that, because a model gives a quantitative description of the observed behaviour of a real system, therefore physical elements corresponding to the components of the model must necessarily exist in that system. Neither is there anything particularly sacred about the Newtonian liquid and Hookean solid. These are abstractions, ideals in which the relations between stress and rate of strain, and stress and strain, are the simplest possible mathematically. Close approximations to the ideals are shown by a fair number of materials under certain conditions of experiment, but there seems no philosophical reason for believing that they are necessarily the bricks from which the real world is constructed.

There is a rather close parallel to this in the field of astronomy. The motions of the planets are far too complicated to permit of precise analytical formulation. What the astronomer does is to assume a simple form of motion that he can readily treat, and then to apply correction after correction until the result is brought sufficiently closely to the observed facts. These corrections have, for the most part, a theoretical foundation and the values of the relevant constants can often be predicted purely by Newtonian mechanics; but they do not correspond to entities having an independent existence and they are little more than mathematical devices enabling us to get an acceptable numerical result.

Thus the motion of the moon relative to any centre of co-ordinates is immensely complicated. Relative to the earth it describes an endless series of open curves. The problem is essentially the celebrated one of three mutually attracting bodies—earth, moon, sun—and has not been solved exactly. This does not mean, however, that the position of the moon at any given time cannot be predicted with considerable accuracy.

Suppose that we wish to determine approximately the moon's geocentric longitude at midnight of the New Year 1950. The first approximation is made by assuming that the moon moves round the earth in a circular orbit with constant angular velocity. The calculation is then one of pure arithmetic, and we find that the moon's *mean* longitude at the period sought is about $64^{\circ}23'$. If one is computing for a remote period of time, this figure must be corrected for the *secular acceleration of the moon's mean motion*. This amounts to only about $10''$ of arc per century, but it is multiplied by the square of the time and becomes considerable over a period of a thousand years or more. This done, we now make our second approximation by assuming the moon to move in an elliptical orbit with variable velocity as given by Kepler's laws. Then it can be shown that the moon's true position in this orbit can be derived from the mean longitude by applying the *equation of the centre*, which is a function of the eccentricity of the orbit and the moon's mean anomaly—that is, its mean angular distance from perigee. The moon's anomaly is found to be $215^{\circ}32'$ and the equation of the centre is $-3^{\circ}28'$. This gives our second approximation to the longitude as $60^{\circ}55'$.

The eccentricity of the moon's orbit is, however, not constant on account of the perturbing action of the sun. The moon is further from the earth at new and full moon than it would be if the sun were not present, but at the first and last quarters it remains at the normal distance. This causes a distortion of the ellipse, and the correction that must be introduced in order to take care of it is called the *evection*. It is a function both of the moon's mean anomaly and of the difference between the mean geocentric longitudes of moon and sun. In the present case it amounts to $+1^{\circ}13'$ and our longitude becomes $62^{\circ}8'$.

We have not yet finished with the action of the sun. When the moon is moving from new to full, it is moving against the gravitational pull of the sun and is retarded. When moving from full to new, it moves with the sun's gravitational pull and is accelerated. Thus its angular velocity is not strictly that given by Kepler's laws, and the correction needed to allow for this is called the *variation*. In our case it amounts to $-37'$ and our longitude "thrice equated" becomes $61^{\circ}31'$. Now the variation is calculated on the assumption that the sun's gravitational pull on the moon is constant. This is not so; the moon is appreciably nearer the sun at new moon than at full, and the gravitational pull is greater. Furthermore, the earth-moon system as a whole is nearer the sun when the earth is at perihelion at the beginning of January than it is when the earth is at aphelion in July. These facts introduce two more corrections known as the *parallactic inequality* and *annual equation* respectively. In our case they are only $-1'$ and $+0'$ so that the longitude becomes $61^{\circ}30'$. This arc is measured along the great circle of the moon's orbit, which is inclined at about $5^{\circ}9'$ to the plane of the ecliptic. The *ecliptic longitude* is thus obtained by solving a spherical triangle and is found to be $61^{\circ}23'$. This is within $2'$ of the value of $61^{\circ}24'57''$ given in the ephemeris—that is, within one fifteenth part of the moon's diameter—and at this point we can conveniently stop. In order to obtain the longitude correct to a tenth part of a second of arc, a considerable number of such correcting terms must be evaluated and in fact Brown's *Tables of the Moon* contain about 1500 of them, so that the task of computing an annual ephemeris is a formidable one.

This is a digression, but the subject is probably not familiar to most rheologists and it does furnish us with a good example of the way in which numerical solution of an immensely complex problem can be obtained by semi-empirical means. The justification of the astronomers' methods is the *Nautical Almanac*. The evection, variation and other terms have no independent physical existence however and *in fact* the moon moves in a continuous, smooth, open curve guided at any instant by the resultant force of the several gravitational pulls due to earth, sun and major planets. In similar manner, our springs and dashpots may be useful if they enable us accurately to predict the rheological behaviour of a material under given conditions, but they do not necessarily give us an insight into the molecular structure of such systems.

V. G. W. HARRISON.

Mr. W. Lethersich.

We are sorry to have to report the death of Mr. W. Lethersich on March 2, after several months of illness. Though not actually a founder member, he was one of the oldest members of the British Rheologists' Club, joining us towards the end of 1941. Actively contributing to a number of our meetings, he soon became well-known and very well-liked. He will be sadly missed and our sympathy is extended to his family and colleagues.

Deutschen Rheologischen Gesellschaft.

We learn with interest of the formation of the German Society of Rheology in Berlin on 5th October 1951. It is perhaps significant of our national characteristics that our German colleagues start off with an imposing Constitution and set of rules, whereas the British Rheologists muddled along very well for over ten years without any rules at all! We hope to give details of this new Society in the next Bulletin. In the meantime, we send greetings to the German rheologists, wishing them success in their venture; and if we can help them in any way or collaborate in the field of rheology, we shall be delighted to do so.

We learn also of moves to establish rheological societies in India and Japan, and will report more of these when we have had time to get in touch with the respective organizers.

"All symbols, i.e. ideographs, are geometrical expressions of thought. So figures are expressions of numbers, as numbers are of quantitative relations. When the astronomer affirms that the planets move in elliptical orbits, he is employing a symbol and expressing a quantitative relationship . . . He finds it convenient to posit a symbolical or fixed focus in the sun and a kenofocus in space. The demonstration is elaborate. It answers to observed phenomena. But so did the epicycle of Ptolemy. The ancient Chinese formulated a theory of eclipses which was found to be workable and in line with the events, but they had no conception of the earth as a spheroid. So, whether it be epicycle, ellipse or cycloidal curve, it is pure symbolism; an expression of quantitative relationship, not necessarily of fact.

"Whatever science we may study we shall find that it has its own terminology, its symbolism, and its empirical methods. Mathematics, as the basis of all science, is itself a universal symbolism, a language into which all knowledge is eventually translated and rendered communicable. The key to all knowledge is in the science of numbers."

W. GORNOLD.

RHEOLOGICAL MODELS:

a historical note

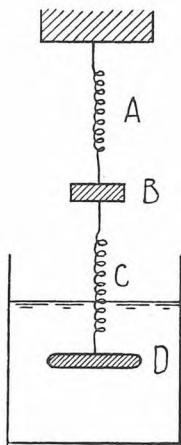
M. REINER

Institute of Technology, Haifa, Israel.

Mechanical models have been widely used for the representation of the rheological behaviour of complex systems. Mises (1) named these after the scientists who first postulated their existence and Reiner (2) followed his example. It is now widely accepted practice to speak of the Newtonian (viscous) liquid, the Hookean (elastic) solid and the St. Venant (plastic) solid. These are represented by a dashpot (N), a spring (H) and a friction element (St.V) which by coupling in series (—) or in parallel (|) make up the Maxwell (M), Kelvin (K) and Bingham (B) bodies, the second also named after Voigt, in accordance with the "structural formulas."

$$\begin{aligned} M &= N - H \\ K &= N | H \\ B &= N - \text{St.V} - H \end{aligned}$$

This nomenclature, adopted because of its obvious advantages, has recently been criticised by Nadai (3) who says: "The association of the names of certain investigators with simple mechanical properties of materials is a . . . practice which should not be encouraged if for no other reason than because the authorship of thought so frequently is doubtful in its origin." It is not to be assumed that Dr. Nadai will succeed in discouraging rheologists to use such a term as "Newtonian liquid" to which he takes exception, but his criticism suggests some little historical research, considering that there is no agreed terminology for materials more complicated than those mentioned above.



2. It appears that the first to use mechanical models consisting of elastic and viscous elements were Poynting and Thomson in their *Text-Book of Physics* which first appeared in 1902 (4). In order to illustrate the phenomenon of elastic after-effect in a glass fibre they proposed a mechanism as shown in the figure. "A is a spring, from the end, B, of which another spring C is suspended, carrying a damper D, which moves in a very viscous liquid. If B is moved to a position B' and kept there for only a short time, so short that D has not time to move appreciably from its original position, then when B is let go it will return at once to its original zero, for D has not moved, so that the conditions are the same as they were before B was displaced. If, however, B is kept in the position B' for a long time, D will slowly move off to a position D', such that D' is as much below B' as D was below B. If now B' is let go it will not at once return to B, for in this position the spring between B and D is extended, B will slowly move back towards its old zero, and will only reach it when the slow moving D' has returned to D."

It will be seen that this model can be represented by the structural formula

$$PTh = H | (N - \dot{H})$$

We may name an ideal material behaving in such a way a "Poynting and Thomson Body."

3. Two years later Trouton and Rankine (5) investigating the behaviour of a lead wire in torsion tried to understand it by actually constructing a model as follows: "Two thin rubber bands hanging from above helped to support a crossbar to which a weight could be attached. Between these in the centre, fixed upright on the crossbar, was a long cylinder filled with a thick oil. A piston hung from above by a strong rubber band worked in this cylinder." This obviously is a PTh body, where H—N represents the strong rubber band cum piston and H the thin rubber bands.

They then continue: "... in order to make the model more complete, one could add,

say, a piston working in a cylinder of oil attached below, the weight itself being hung from beneath the cylinder." This makes for the structural formula

$$TR = N - PTh = N - H | (N - H)$$

and we may name an ideal material behaving in such a way a "Trouton and Rankine Body."

4. Burgers (6), to whose detailed investigation we owe the popularity of rheological models, proposed for the most complex systems the model

$$Bu = K - M$$

and we may name an ideal material behaving in such a way a "Burgers Body."

Lee and Markwick (7) found that the rheological behaviour of asphalt can be described by means of a Bu-body.

If we take these models *literally* as *mechanisms* we can develop the last formula as follows :

$$Bu = M - K = (N - H) - (N | H) = N - \left\{ H - (N | H) \right\} = N - \left\{ (H - N) | H \right\} = TR$$

However, as Burgers pointed out, "the 'models' . . . have no other purpose than to serve as an illustration of the properties of certain substances," and their meaning is rather symbolical. The final aim of a rheological investigation is the establishment of the *rheological equation of state* of the material connecting the tensors of stress, strain and flow and their time derivatives. To this aim rheological models via structural formulas can help, but the development of a structural formula may sometimes be misleading.

More especially one should keep in mind that the M-body is essentially a one-phase system in which the dashpot does not represent a viscous phase in the material but the *relaxation* of elastic stresses. Similarly, if we write $N | H$ the dashpot may represent the viscosity of the viscous phase in an elastic gel, and this is the model which Kelvin had in mind. If however the dashpot is a symbol for solid viscosity in a one-phase system, the model stands for a Voigt-body. Only when the elastic strain is infinitesimal can these two be identified.

REFERENCES :

- (1) R. V. MISES. *Proc. Int. Congr. Appl. Mech.* 1930.
- (2) M. REINER. *J. Sci. Instrum.* 1945, **22**, 127.
- (3) A. NADAI. *Theory of flow and fracture of solids*, New York, 1950.
- (4) J. H. POYNTING and J. J. THOMSON. *Properties of Matter*, London, 1902.
- (5) F. TROUTON and A. O. RANKINE. *Phil. Mag.* (VI), 1904, **8**, 555.
- (6) J. M. BURGERS. *First Report on Viscosity and Plasticity*, Amsterdam, 1935.
- (7) A. R. LEE and A. D. H. MARKWICK. *J. Soc. Chem. Ind.*, 1937, **56**, 146T.

SUMMARIES OF PAPERS

read at meetings of the Society.

Elementary Aspects of Rubber Abrasion

A. SCHALLAMACH.

British Rubber Producers' Research Association, Welwyn Garden City, Herts.

The problem of rubber abrasion has been attacked from two sides. On the one hand, very simple abrasion experiments have been carried out in which rubber was scratched with a needle; on the other hand, the so-called "abrasion pattern" found on abraded rubber surfaces has been examined in detail and its significance has been studied.

The scratching experiments were made under various normal thrusts on the needle and at various velocities, provision having been made for the recording of the instantaneous tractive force on the needle. The traces produced by the needle and the corresponding tractive force-time records depend pronouncedly on the nature of the compounds under investigation. In particular, the traces on pure gum vulcanizates are always discontinuous, and the time dependence of the tractive force is given by saw-tooth curves, but the traces on carbon loaded compounds of the tyre tread type are continuous, and the tractive force is subject to much smaller fluctuations than in the case of the pure gum compounds. However, the surface damage on all types of rubbers is characterized by the fact that small pieces of partly detached rubber are found in the wake of the needle which are easily removed when the surface is attacked again. It has been possible to explain the results qualitatively in terms of hardness, friction and tear-resistance of the samples.

The abrasion pattern appears both on samples which have been abraded in the laboratory, and on tyres. It consists of an array of nearly parallel ridges oriented at right angles to the direction of abrasion. A cross section through an abraded rubber surface reveals that the profile of the ridges is asymmetrical, and it is possible to identify the direction in which the abrasion has moved relative to the abraded surface. The spacing of the ridges increases with increasing normal pressure, and it has been discovered that during abrasion the pattern moves as a whole across the surface of the sample in the same direction as the abrasive. The pattern has proved to be an important clue to the conditions under which abrasion occurs on the road. Its origin is most probably a consequence of the combination of high elasticity and high coefficient of friction which are characteristic of rubber.

Paper read 4th January, 1952.

Investigation of Fretting Corrosion.

K. H. R. WRIGHT.

D. S. I. R. Mechanical Engineering Research Organisation,
Lubrication and Wear Division.

The paper describes a series of experiments on the subject of fretting corrosion, an expression used to describe the surface damage occurring between two closely fitting surfaces subject to slight vibrational movement. A fundamental approach has been adopted and care taken over the control of the environmental or mechanical conditions of the experiments. The emphasis of the research has been placed upon obtaining quantitative measurements of the degree of fretting damage and it has been shown that considerable reproducibility can be obtained, thus making it possible to correlate this measurement with such variables as total number of oscillations, load, or atmospheric humidity.

In addition to the total amount of damage occurring during an experiment, measure-

ments have also been made, which enable the form of the pits to be examined, and it has been found that these vary under the different experimental conditions. Thus, in the initial stages of fretting when the corrosion is localised, increasing the number of oscillations increases both the area and depth of the pits almost equally, whereas the effect of increasing the load has the result of primarily increasing the area of the pits. Humidity variations have also been shown to have pronounced effect on both the form and total amount of damage, and this probably accounts for the large discrepancies between the observations obtained by different workers.

Although most of the measurements have been made using lapped K.9 steel specimens, some results were obtained with other materials such as chromium, nickel and gold. Nickel plating has been advocated as an anti-fretting surface, but the experiments clearly show this to be ineffective, unless it can be assumed that the nickel plating has the additional effect of reducing the slip between the two surfaces.

The use of lubricated phosphated surfaces can be strongly recommended as an inhibitor of fretting corrosion, as emerges from the results obtained with this form of surface preparation rubbing against a steel flat.

Some additional experiments have been carried out with K.9 steel surfaces to establish the significance of the absorption and diffusivity of oxygen in surrounding liquid media. It has been shown that complete immersion in B.P. paraffin which is either saturated or free from water vapour, can successfully prevent the formation of the oxide debris $\alpha\text{Fe}_2\text{O}_3$, but the use of n-hexane, which is an inert liquid of high oxygen solubility and low viscosity, cannot do so. In particular, it has been observed that although the initial oxide formed is Fe_3O_4 , continued oscillation gives rise to the characteristic red brownish oxide $\alpha\text{Fe}_2\text{O}_3$.

Paper read 4th January, 1952.

Three Years Experience with a new Micro-Abrasion Tester.

P. GRODZINSKI

Industrial Distributors (Sales) Limited,
Diamond Research Department, 32, Holborn Viaduct, E.C.1.

The approach to rapid wear testing is made by an abrasion method using a high speed grinding wheel. In this way, material is more rapidly removed under much lower loads than in usual wear testing methods working with low speeds and high pressures.

The new micro-abrasion tester (British Patent 665429, German Patent 859512) consists of a wheel of 25.4 mm. diameter rotating at 10000 to 15000 r.p.m. The sample is fixed in a balance arm and pressed against the periphery of the preferably double conical wheel with sharp edge for a period of 1 to 15 sec. The tester was originally developed for determining vector hardness differences in diamond surfaces but proved to be very useful for practically all hard materials. The indication for the abrasion resistance of a certain material is the length of the abrasion mark. Theoretical investigations show that the removed volume is proportional to (length)⁵, whereas investigation of the actual shape revealed that the cavity is more in the form of the cupola of an elliptical paraboloid and that therefore the removed volume is proportional to (length $\times$ width $\times$ height). As an empirical measure usually the length of mark is used, as the height is difficult to measure except by interferometric methods. When varying the test time, the load and the speed, and plotting the obtained values against the length of mark in a log-log diagram, a straight line relationship was obtained.

The original wheel consisted of cast iron to which fine diamond dust of 0 - 2 micron size suspended in olive oil was applied. A number of other wheels were tried out, such as diamond prepared dental wheels (grain size 80 to 100 mesh), sintered carbide, and alumina.

Best results hitherto were obtained with sintered carbide wheels impregnated with diamond powder. A sintered carbide wheel with a nickel bond is used. These wheels maintained their abrasiveness even on hard materials such as sapphire and sintered carbide itself.

Whilst the first tests were carried out on diamond and hardness differences in diamond surfaces could be clearly demonstrated, further tests were carried out on silicon carbide, corundum, ceramic glazes, sintered carbide, etc.

Usually the abrasion resistance of a particular material was compared with micro-indentation tests. In the group of very hard materials, high indentation hardness goes together with high abrasion resistance. Hitherto no exception has been found. However, the mechanism of abrasion and indentation seems to differ significantly with softer materials, such as when comparing stainless steel with aluminium bronze. The abrasion tests were also tried to correlate with friction tests, in particular dynamic friction and the micro-abrasion tester was adapted for determining surface friction. Other tests which can be tried out were as follows :

(a) replacement of the grinding wheel, abrading on its whole surface by a single point cutter, preferably a shaped diamond (micro-cut).

(b) application of a continual tangential feed in the direction of the periphery of the wheel, in particular used with composite materials, such as granite.

(c) production of marks in surfaces of actual machine components.

When the surface is worn the length of mark is reduced and thus the thickness of the layer removed by wear can be determined.

Method (a) can be used either for testing the machinability of a certain material, or for producing the marks according to method (c). Method (b) may find application in testing the bulk hardness of composite materials, such as stone materials.

Paper read 4th January, 1952.

Experiments on the Abrasion Hardness of Diamond using a Micro-abrasion Tester.

MRS. E. WILKS.

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There are two mechanical effects to be considered in micro-abrasion tests. From interference pictures of abrasion marks it could be concluded that the wheel moved considerably during operation, both in the direction of the abrasion mark and at right angles to it; the latter movement was more pronounced when it was difficult to produce an abrasion mark in the surface. Sometimes the shallowest marks were also the widest. A lantern slide was shown of an interferogram across a cube face : one end of the mark appears well defined, the other is ragged, and the direction of wheel rotation corresponds to the well-defined end.

The depths of the marks were found to be considerably less than the depths computed from the lengths of the mark and the wheel dimension. Further, the included angle of the mark was 176° whereas the included angle of the wheel was 110° . The first effect may be due to the longitudinal and the second to the lateral wheel motion. However, the second effect is very large and the possibility of elastic wheel deformation must not be ignored.

Concerning the abrading effect on the diamond surface, it has already been mentioned that the marks are shallow; the deepest is of the order of $5\frac{1}{2}$ light waves ($5461 \text{ \AA}$) deep, but the sharp fringes also show that the mark is highly polished. For other tests it was shown that when diamond is abraded in "unfavourable" directions, no polish results. No fringes were obtained on such surfaces. Thus abrasion consists in the removal of diamond particles without surface flow, and along favourable directions a simultaneous polish is effected.

A further point shown by the fringes is that the outlines of the abrasion marks are very sharp and no large scale misorientation of the surrounding area has occurred.

RESULTS OF THE ABRASION TEST ON DIAMOND.

Variations in abrasion hardness were deduced from the measured depth per revolution of the wheel. It was confirmed that abrasion takes place almost only in directions parallel to crystallographic axes. Thus it is normally not possible to abrade octahedron faces as they are inclined to all three axes.

The cube faces are parallel to two axes and although abrasion was effected in the four corresponding directions, there was not equality of ease of abrasion between them.

The dodecahedron faces of only two stones were tested. Of these one could be abraded in both directions parallel to the crystallographic axis, but the other one only along one direction. This may be due, however, to the stones not being exactly oriented.

It was also found that the dodecahedron faces were easier to abrade than the cube faces. Finally it was found that of two stones the dodecahedron face of one was easier to abrade than that of the other, whereas the reverse was true of the cube faces. This suggests that comparisons between stones as to abrasion hardness values may be misleading.

Paper read 4th January, 1952.

The Wear of Wire-Drawing Dies.

J. G. WISTREICH.

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Wire drawing means elongating metal of threadlike form by pulling it through a die with a tapered hole in it. Owing to the length of wire, it is not drawn straight but wrapped round a motor-driven capstan, and is handled in coil bundles or on spools. Before and after drawing proper, several ancillary operations have to be performed. To reduce the time needed for such operations, the process is made practically continuous by welding a new coil of wire on to the preceding one.

Only a limited reduction in size is possible because the force needed to pull the wire through the die must not cause the tensile stress in the wire between die and capstan to exceed its yield stress. In practice the diameter of the drawn wire is about $\frac{7}{8}$ of the original diameter, so that as many as 50 passes may be required to produce wire of, say, 0.05 mm. diameter. Modern machines are therefore built so that several passes succeed each other continuously. If one of the dies in such a continuous multi-pass machine wears out, the machine has to be stopped, the wire cut, repointed, threaded through the new die, and joined to the other piece. It is this interruption which constitutes the most important economic reason for wishing to keep die wear to the minimum. The purpose of our investigations has been to reduce the frequency of die failures rather than to improve the median die performance.

A die is taken out of service either because the tolerance limit on the wire size is exceeded, or because of scoring of the wire surface. We have concentrated on the latter because the former can be postponed by modification of the die profile.

The pressures involved in drawing are of the order of the yield stress of the metal and, although most wires are drawn "cold," the temperature of the die-wire interface is high because of the high speeds of drawing. For example, when 1 mm. diameter high-tensile steel wire is being drawn at 12 m/sec this temperature is estimated to be about 600°C. Ordinary lubricants are thus unsuitable and one resorts to solid substances such as soaps and various metallic and non-metallic coats. Little is known about lubrication in wire drawing, but it probably varies from dry friction to quasi-hydrodynamic lubrication, depending on the particular circumstances. Reasons for this belief are: (1) Virgin

metal is being exposed during the passage of the wire through the die. (2) All good wire drawing lubricants are good boundary layer lubricants and conversely, lubricants for the hydrodynamic regime are unsuitable for wire drawing. (3) The amount of lubricant that passes through the die is often much greater than would be expected from pure boundary lubrication and the estimated coefficient of friction is often correspondingly low.

The average life of dies varies a great deal from one mill to another, and even when conditions are steady by industrial standards, the performance of dies usually varies by a factor of ten or even a hundred. Short lives are more frequent than long. In fact, the frequency distribution approximates to a lognormal one. We are now of the opinion that die quality cannot account for the great variability of performance and the predominance of short lives.

The wear in worn dies is not uniform along the internal bore but follows a characteristic pattern. The surface remains highly polished over a large area bounded by two narrow regions of rough surface. On the whole, wear proceeds most rapidly near the wire entry and exit. The groove near the wire entry gives rise to longitudinal scoring of the die, which in turn ruins the surface of the wire. The formation of this groove is termed "ringing." Ringing starts in the plane of first contact between wire and die and the stress gradient at wire entry is in some way responsible for it. By applying tension to the incoming wire (back pull) amounting to about 70% of the initial yield stress of the wire and thus reducing the die pressure by a factor of three, the shape of the ring was modified and its size reduced.

On the microscopic scale, evidence has been obtained to show that grains of tungsten carbide are plucked out of the die, get embedded in the wire and are ploughed through the die.

The variability of die performance and preponderance of short lives suggests that the wear encountered is the outcome of inadequate lubrication. One gets erratic and intermittent destruction rather than progressive uniform wear. This situation is not inevitable and it is possible that lubrication can be improved. The most likely explanation of "ringing" is in terms of static failure of the die material, and a more elaborate explanation can be put forward in terms of fatigue failure. It can be argued that owing to small differences in wire diameter and slight movement of the wire, the plane of contact is not stationary, and elements of the die in this region are periodically stressed and unstressed. Finally, one might perhaps explain ringing in terms of cold welding of the type made familiar by the work of Bowden, Tabor and collaborators. This hypothesis could account not only for ringing, but also for the pronounced wear of the die exit portion: on the other hand it is not known whether it can be reconciled with the observed effect of back tension in reducing ringing.

(Summary prepared by V.G.W.H.).

Paper read 4th January, 1952.

RHEOLOGY ABSTRACTS

2347. A contribution to the methods of measuring the plasticity of clays.

R. AHLBERG. *Trans. Chalmers Univ. Techn. (Gothenburg)* 1951, No. 119.

Two English clays and clays with pure cation complexes made from them investigated in Hoesppler viscometer.

2348. Non-Newtonian flow of dilute polymer solutions. III. Sodium carboxy methyl cellulose in solutions of sodium chloride.

F. AKKERMAN, D. F. T. PALS AND J. J. HERMANS. *Rec. Trav. Chim. Pays-Bas*, 1952, **71** (1), 56.

A direct and straightforward method is used to derive the influence of the shearing stress on the intrinsic viscosity from the experimental data without introducing empirical or semi-empirical relations. It can be shown that the method of plotting $(t-t_0)/t_0c$, where t is the flow time and c the concentration, is wrong. The application to carboxy methyl cellulose in dilute salt solutions reveals a pronounced effect of small shear rates on the intrinsic viscosity. On comparing with existing hydrodynamic theories it is found that even the fully extended length of the polymer molecule would be too small to explain the results.

AUTHORS.

2349. Formula for creep curves of metals.

E. N. DA C. ANDRADE. *Nature*, 1951, **168**, 1007.

2350. The viscosities of liquid lithium, rubidium and caesium.

E. N. DA C. ANDRADE AND E. R. DOBBS. *Proc. Roy. Soc. A.*, 1952, **211**, 12.

2352. The mechanical behaviour of single crystals of certain face-centred cubic metals.

E. N. DA C. ANDRADE AND C. HENDERSON. *Phil. Trans. A.*, 1951, **244**, 177.

2353. Viscosity of binary liquid mixtures.

N. L. BALAZS. *Rec. Trav. Chim. Pays-Bas*, 1951, **70** (5), 412.

An approximate theoretical deduction is given for the viscosity coefficient of binary liquid mixtures combining a modified theory of Eyring for viscous flow with the statistical model due to Guggenheim for strictly regular solutions, using the Bragg-Williams approximation.

2354. Flow of gases and vapours in a porous medium and its bearing on adsorption problems. I. The steady state of flow.

R. M. BARRER AND D. M. GROVE. *Trans. Farad. Soc.*, 1951, **47**, 826.

A study has been made of the steady state of flow of He, Ne, A, Kr, H₂, O₂, N₂, NH₃, CCl₄ and SO₂ through a bed of small nearly spherical synthetic analcite crystals.

2355. Flow of gases and vapours in a porous medium and its bearing on adsorption problems. II. Transient flow.

R. M. BARRER AND D. M. GROVE. *Trans. Farad. Soc.*, 1951, **47**, 837.

By measuring the time-lag in setting up the steady flow one may measure the diffusion coefficients of gases in a porous medium and obtain a mean pore radius and an internal surface of the porous medium independently of all steady state methods.

2356. **Compressibilities of cubic crystalline powders: a new method of measurement.**

S. BHAGAVANTAM AND T. SESHAGIRI RAO. *Nature*, 1951, **168**, 744.

2357. **Plasticity of wool**

R. W. BURLEY AND J. B. SPEAKMAN. *Nature*, 1952, **169**, 371.

2358. **Viscous buttressing.**

F. CHARRON. *C. R. Acad. Sci. (Paris)*, 1951, **233**, 1170.

A comparison between the forces of viscosity under instantaneous pressure and those of friction. SCI. ABSTR.

2359. **The formation of an aerosol by condensation of a dilute vapour in a carrier gas.**

J. CORNER. *Proc. Roy. Soc. A.*, 1952, **211**, 417.

2360. **Studies in Newtonian flow. II. The dependence of the viscosity of liquids on free-space.**

A. K. DOOLITTLE. *J. Appl. Phys.*, 1951, **22**, 1471.

2361. **The dynamic modulus of elasticity of regenerated cellulose fibres in relation to large deformation.**

H. DE VRIES. *Appl. Sci. Res.*, 1951, **A3**, 111.

The dynamic modulus of elasticity of regenerated cellulose fibres is studied for its dependence on the spinning stretch and the dry extension of a great number of samples. Two yield ranges in terms of extension of the fibre are distinguished. The structural changes involved are briefly discussed. AUTHOR.

2362. **Non-Newtonian flow of dilute polymer solutions. I. Outline of the method.**

G. DE WIND AND J. J. HERMANS. *Rec. Trav. Chim. Pays-Bas*, 1951, **70** (7), 521.

A method is developed for the study of non-Newtonian behaviour of dilute polymer solutions with a view to extrapolating the results obtained to infinite dilution. This method will be applied in the second part. The use of a capillary viscometer for this kind of work is discussed. As a check on the equation used some measurements with water, benzene and acetone are reported. AUTHORS.

2363. **Non-Newtonian flow of dilute polymer solutions. II. Solutions of cellulose nitrate in acetone.**

G. DE WIND AND J. J. HERMANS. *Rec. Trav. Chim. Pays-Bas*, 1951, **70** (8), 615.

The method outlined in part I is applied to solutions of cellulose nitrate in acetone. It is found that the non-Newtonian character of the flow is strongly dependent on the polymer concentrations, but does not persist at the limit of infinite dilution. In other words, the non-Newtonian character of the flow is not an intrinsic property of the polymer molecule but results from molecular interactions. The concentrations were varied between 0.05 and 0.2 g/100 ml. In one series we went up to 0.8 g/100 ml. The highest gradient attained was about $5 \times 10^4 \text{ sec}^{-1}$. AUTHORS.

2364. **Chain-length distribution studies on nitrated wood and cotton celluloses.**

CONSTANCE EMERY AND W. E. COHEN. *Aust. J. Appl. Sci.*, 1951, **2** (4), 473.

An attempt has been made to determine the long-period molecular structure of cellulose. Evidence is presented to show that disregard of the degree of esterification of the fractions made by the precipitation technique, can cause very great errors in viscosity-distribution curves. Consideration has been given to the applicability of the precipitation technique to celluloses of high average molecular weight. For incompletely substituted nitrates of degree of polymerization about 2000, the usual fractionation procedure is

entirely inadequate and the separation of fractions does not proceed upon the basis of either nitrogen content or viscosity, but depends in a complex way upon both of these and probably upon other unknown factors. On the other hand, with acid-hydrolysed cotton of low average molecular weight, fractionation is shown to take place in general as predicted by the Schulz equations.

AUTHORS (ABR.).

2365. The solution of boundary value problems by multiple Laplace transformations.

T. A. ESTRIN AND T. J. HIGGINS. *J. Franklin Inst.*, 1951, **252**, 153.

2366. A problem in dynamic plasticity: the enlargement of a circular hole in a flat sheet.

W. FREIBERGER. *Proc. Camb. Phil. Soc.*, 1952, **48**, 135.

2367. On the existence of plane periodic irrotational motions of a heavy incompressible liquid.

R. GERBER. *C. R. Acad. Sci. (Paris)*, 1951, **233**, 1261.

The existence is proved, under certain conditions, of types of flow which are periodic in a horizontal direction, corresponding to steady flow of a perfectly fluid sea over a corrugated bed.

SCI. ABSTR.

2368. On non-steady laminar flow of an incompressible viscous fluid in circular-cylindrical tubes.

W. GERBES. *Z. angew. Phys.*, 1951, **3**, 267.

On the assumption of rectilinear axially-symmetric flow, and an arbitrary variation of applied pressure with time, a general expression is obtained for the Laplace transform of the velocity in terms of that of the pressure-gradient. The velocity profiles at different times after the sudden application of a constant pressure, and at different times after its subsequent removal, are computed. The amplitude of oscillation in the velocity is calculated as a function of distance from the axis when the applied pressure varies sinusoidally at different frequencies. This amplitude decreases rapidly with increasing frequency, and the velocity is 90° out of phase with the pressure under all conditions.

SCI. ABSTR.

2369. General theory of small elastic deformations superposed on finite elastic deformations.

A. E. GREEN, R. S. RIVLIN AND R. T. SHIELD. *Proc. Roy. Soc. A*, 1952, **211**, 128.

2370. A note on estimating yield-point loads in a plastic-rigid body.

R. HILL. *Phil. Mag.*, 1952, **43**, 353.

2371. A vibrating cantilever method for the investigation of the dynamic elasticity of high polymers.

K. W. HILLIER. *Proc. Phys. Soc. (Lond.) B.*, 1951, **64**, 998.

2372. Experiments with oscillating disc systems in liquid helium II.

A. C. HOLLIS-HALLETT. *Proc. Roy. Soc. A*, 1952, **210**, 404.

2373. Plasticity.

J. M. HUMPHRYS. *J. Canad. Ceram. Soc.*, 1951, **20**, 26.

A general discussion on the nature of plasticity and plastic flow, water films around clay particles, work-hardening and other features of plastic clays.

B.C.R.A.

2374. Contribution to the study of incompressible fluids in turbulent motion.

J. VAN ISACKER. *Inst. Roy. Met. Belge Mem.*, 1951, No. 43.

2375. Measurement of plastic flow in moulding sands.

A. JAMIESON. *Found. Tr. J.*, 1951, **91**, 271.

Although the "feel" of a sand changes continuously during milling, the strength as measured scarcely alters; it is suggested that what is actually altering is the capacity of the material to absorb work. To test this hypothesis, a comparison machine was built so that deformation readings could be taken during the application of a load to a sand specimen; the machine is a modification of the Buchanan compression tester. Plastic flowability is defined as the ability of a moulding material to take up new positions when subjected to an external stress; it may be represented by strain per unit stress. The modulus of plasticity is a measure of the ability of the grains of a moulding material to resist displacement when subjected to an external stress; it may be represented by stress per unit strain. A high flowability indicates low plasticity and *vice versa*. The results of tests on some sands are shown graphically. B.C.R.A.

2376. The non-Hookean interaction of a dislocation with a lattice inhomogeneity.

M. A. JASWON AND A. J. E. FOREMAN. *Phil Mag.*, 1952, **43**, 201.

2377. A calculation of the elastic shear constants of β -brass.

H. JONES. *Phil. Mag.*, 1952, **43**, 105.

2378. Mobility in a sorbed layer. I. The flow of gases and vapours through porous media.

W. M. JONES. *Trans. Farad. Soc.*, 1951, **47**, 381.

Theoretical equations are given for the surface flow of an ideal two-dimensional gas, treating the porous material as a bundle of fine capillaries. It is concluded that in addition to the Poiseuille and Knudsen expressions for flow there is needed an expression for the flow of sorbed molecules over the capillary surfaces. G.S.

2379. Mean first-passage times of Brownian motion and related problems.

G. KLEIN. *Proc. Roy. Soc., A* 1952, **211**, 431.

2380. On the foundations of certain theories of turbulence.

M. Z. V KRZYWOBLOCKI. *J. Franklin Inst.*, 1951, **252**, 409.

2381 A contribution on plasticity measurements.

M. LINSEIS. *Sprechsaal*, 1951, **84**, 259.

Plasticity is mainly determined by two factors, cohesion of individual particles and their capability of sliding against each other without losing contact. A method for the measurement of plasticity based on these two properties was evolved. As a criterion for the cohesion of particles tensile strength was chosen, and for shear resistance the force required to drive a knife through a clay column. Measurements were carried out on eight samples of German kaolins and clays to determine tensile strength and shear resistance with water content increasing in increments of 5%. Results are tabulated. Another table shows the dependence of maximum tensile strength on the content of particles less than 1μ . Numerous graphs are given on which plasticity of individual raw materials can be deduced from the position of the maxima of corresponding curves. B.C.R.A.

2382. A new method of solving the Born-Green equation for the radial distribution function.

A. G. McLELLAN. *Proc. Roy. Soc. A* 1952, **210**, 509.

2383. Friction and wear in the physics of surfaces.

A. MARCELIN. *J. Phys. Radium*, 1951, **12**, 1A.

The friction between two solid surfaces is initially due to the roughness of the surfaces. Wear results in the removal of asperities, causing a friction dependent on the

molecular forces between the two surfaces. Studies of the friction and wear with and without lubricating films are described. It is found that transfer of material between the surfaces always takes place with dry friction but does not occur in the presence of a lubricant. It is estimated that the order of magnitude of the range of the surface forces is 10^{-7} cm. SCI. ABSTR.

2384. The viscosities of aqueous solutions of amino acids.

L. S. MASON, R. M. KAMPMAYER AND A. L. ROBINSON. *J. Amer. Chem. Soc.*, 1952, **74**, 1287.

A general correlation exists between the differential activation energy for viscous flow and the differential entropies of dilution. E.W.J.M.

2385. Plastic deformation and the Meyer constants of metals.

M. A. MEYER AND J. BLOK VAN LAER. *Nature*, 1952, **169**, 237.

2386. Cylindrical and rotational co-ordinate systems.

P. MOON AND D. E. SPENCER. *J. Franklin Inst.*, 1951, **252**, 327.

2387. On the nature of the initial deformation.

G. MÜLLER AND W. ENGELHARDT. *Ann. Phys. (Lpz.)*, 1951, **9**, 357.

Small extensions of a spiral copper spring are used to obtain strain-time curves at various temperatures. Kuhlmann and Masing's equation (*Z. Metallkde*, 1948, **39**, 361) is used to represent the results. SCI. ABSTR.

2388. Recent progress in the plastic methods of structural analysis.

B. G. NEAL. *J. Franklin Inst.*, 1951, **252**, 383.

2389. Experimental studies on the internal friction in solids.

T. NISHIHARA AND H. MIKI. *Tech. Rep. Engng. Res. Inst., Kyoto Univ.*, 1951, **1**, 1.

A dashpot, spring and friction element model is proposed and investigated in some detail. The log decrement is calculated, and its dependence on frequency is compared with the experimental results obtained on cold drawn brass and 0.8% carbon steel. Both drawn and quenched samples of the latter were tested before and after annealing at various temperatures. These results are also compared with Zener's thermo-elastic theory. Some details of the experiments are given; the log dec. was determined from a photographic record of the amplitude of transverse vibrations of freely suspended specimens. SCI. ABSTR.

2390. Viscosity of silicate glasses.

M. V. OKHOTIN. *Stek. Keram.*, 1951, **8** (6) 5.

In Na-silicate glasses, if viscosity is constant, temperature coefficient varies linearly with Na_2O content in the range 29 — 44% Na_2O , and curvilinearly if the Na_2O content is 22 — 29%. For a glass of given composition in the range 22 — 44% Na_2O , it is possible to plot from five points a curve relating $\log \eta$ to the temperature. The viscosity of glasses in the system Na_2SiO_3 — PbSiO_3 — SiO_2 was determined by the torsion method; with a constant viscosity, temperature coefficient varied linearly with PbO concentration (mol.%). On this basis the temperature for a given viscosity and fixed composition can be determined with sufficient accuracy from the equation $t = a + bc$, where t is temperature, c is concentration of PbO , and a and b are constants (their values are tabulated). After the temperature for a glass of a given composition with viscosity 10^2 , 10^3 and 10^4 poises has been calculated the dependence of $\log \eta$ on temperature can be expressed by a curve drawn through these three points. B.C.R.A.

2391. The crystallographic aspect of slip in body-centred cubic single crystals. Interpretation of experiments.

A. J. OPINSKY AND R. SMOLUCHOWSKI. *J. Appl. Phys.*, 1951, **22**, 1488.

2392. The adiabatic elastic constants of rock salt.

W. C. OVERTON, JR. AND R. T. SWIM. *Phys. Rev.*, 1951, **84**, 758.

2393. A note on the measurement of damping in vibrating rods.

G. G. PARFITT. *Brit. J. Appl. Phys.*, 1951, **2**, 327.

2393. Microwave absorption and molecular structure in liquids: effects of viscosity.

A. J. CURTIS, P. L. MC GEER, G. B. RATHMANN AND C. P. SMYTH. *J. Amer. Chem. Soc.*, 1952, **74**, 644.

Dipole—dipole forces are found to play an important part in hindrance of molecular rotation, and the distribution of relaxation time tends to increase with increasing viscosity and is influenced by molecular shape and size.
E.W.J.M.

2394. An investigation into the rheological properties of bitumen. I. Maxwell-body and elastic dispersions.

M. REINER. *Bull. Res. Coun. Israel*, 1951, **1**, 5.

It is shown that while for infinitesimal elastic strain e , no difference in the rheological behaviour of sols and gels can be distinguished, the first represented by a structural formula of the type: $S = N - K = N - (H/N)$, the second by $G = N/M = N(H - N)$; this is not so when the strain is finite. In the latter case, the true viscous resistance of a prism of length l in extension is measured by $f = \dot{l}/l$, while the "viscosity" due to Maxwellian relaxation of the stresses is measured by e which is equal to f only when the strain is measured in accordance with Hencky. The measure of the strain e , when finite, not being unequivocal, different flow curves will result from different measures of strain, even in pure extension. In simple shear, an elastic sol will exhibit flow curves similar to those in pure deformation, while an elastic gel will simulate variable viscosity. Rheological observations of large deformations of materials which may exist in the sol and gel state, such as bitumen, therefore supply information from which an insight into the structure of the material can be gained.
AUTHOR.

2395. Frictional resistance of discs rotating in a liquid, and the integral equations applied to the problem.

D. RIABOUCHINSKY. *C. R. Acad. Sci. (Paris)*, 1951, **233**, 899.

2396. The free energy of deformation for vulcanised rubber.

R. S. RIVLIN AND D. W. SAUNDERS. *Trans. Farad. Soc.*, 1952, **48**, 200.

Measurements on the load-deformation relations in pure shear and in simple extension for a number of vulcanizates covering a wide range of hardness are reported. The measurements are used to study the manner in which the dependence of the free energy of deformation upon strain invariants I_1 and I_2 changes with the amount of cross linking.
G.S.

2397. Motion of fluids through porous media.

P. L. ROMITA. *Ric. Sci.*, 1951, **21**, 1978. *In Italian.*

To determine the limits of validity of the Darcy law, the author takes into consideration and compares the results of the researches on filtration carried out during the last 20 years, that have reached and passed these limits covering at least part of the transition range between linear and quadratic resistance, particular attention being paid to the beds of loose material. The experimental results are reduced to a common basis by taking into account the porosity of the bed, with a method which proves to be particularly effective and leads to the definition of a generalized Reynolds number for the filtration processes. The limit of validity of the Darcy law is established in terms of this Reynolds number and an expression for the resistance law in the transition range, for beds of spherical or rounded elements, is suggested, on the basis of the examined results and with the support of some results obtained by the author.
SCI. ABSTR.

2398. **The shaping of metal crystals.**
P. R. ROWLAND. *Trans. Farad. Soc.*, 1951, **47**, 193.
2399. **The crystallization of vulcanized natural rubber at low temperatures.**
E. W. RUSSELL. *Trans. Farad. Soc.*, 1951, **47**, 539.
Only the free crystallization of unstretched material is considered. G.S.
2400. **Approximation methods in the theory of visco-elastic behaviour. I.**
F. SCHWARZL. *Physica*, 1951, **17**, 830.
2401. **Approximation methods in the theory of visco-elastic behaviour. II.**
F. SCHWARZL. *Physica*, 1951, **17**, 923.
2402. **The rheology of uterine cervical secretions.**
G. W. SCOTT BLAIR. *Appl. Sci. Res.*, 1951, **A3**, 89.
Presidential address to the British Rheologists' Club, September, 1950.
2403. **On Heisenberg's spectrum of turbulence.**
N. R. SEN. *Bull. Calcutta Math. Soc.*, 1951, **43**, 1.
2404. **The effect of certain reagents upon the properties of bentonite colloids. II. Organic amines.**
W. H. SLABAUGH AND J. L. CULBERTSON. *J. Phys. Colloid Chem.*, 1951, **55** (7), 1131.
An investigation, primarily based upon viscometric analysis, of reaction systems between hydrogen bentonite and organic amines in aqueous media. The results give some indication of the mechanisms of the chemical reactions. It is found that monofunctional amines produce dehydration of the bentonite micelle; with difunctional amines, more complex reactions have been observed. See Abstr. 2208. G.E.B.
2405. **A piezoelectric method for determining Young's modulus and its temperature dependence.**
H. E. STAUSS, F. E. MARTIN AND D. S. BILLINGTON. *J. Acoust. Soc. Amer.*, 1951, **23**, 695.
A resonance method for determining Young's modulus in metals, based on support of the specimen at its central node for longitudinal vibrations, with the supporting rod articulating at its lower end with a piezo-electric crystal, has been developed. Utility of the method was extended by adapting it to measurement of changes in Young's modulus with temperature. AUTHOR.
2406. **The physical properties of amorphous polymer networks.**
L. R. G. TRELOAR. *Chem. and Ind.*, 1951, **45**, 955.
A review of the application of statistical theories to the interpretation of (1) mechanical properties, (2) optical properties, (3) swelling phenomena, of cross linked high polymers. C.C.M.
2407. **Flow through uniformly tapped pipes.**
B. G. VAN DER HEGGE ZIJNEN. *Appl. Sci. Res.*, 1951, **A3**, 144.
After a review of the case of laminar and turbulent flow through a pipe with a porous wall, the following questions have been treated in an analytical way: laminar flow in a pipe and laminar flow through branch pipes, or with discharge through orifices; turbulent flow in a pipe and laminar flow through branch pipes, or discharge through orifices. AUTHOR. (ABR.)
2408. **Statistical thermodynamics of rubber elasticity.**
F. T. WALL AND P. J. FLORY. *J. Chem. Phys.*, 1951, **19**, 1435.

2409. Solutions of some partial differential equations.

L. WEINBERG. *J. Franklin Inst.*, 1951, **252**, 43.

Gives tables for the solution of the Helmholtz equation as a general solution for Laplace, Poisson, wave, diffusion. K.S.

2410. Stress-strain relationship: a mathematical model.

E. J. WILLIAMS AND N. H. KLOOT. *Aust. J. Appl. Sci.*, 1952, **3** (1), 1.

A mathematical model has been devised for the study of the properties of materials under load. It has been shown to yield load-deformation curves very similar in general appearance to those obtained in practice with a variety of materials. The effect of rate of straining indicated by the model is qualitatively similar to that observed with wood.

AUTHOR.

2411. Flow of gas in porous media.

L. H. WILSON, W. L. SIBBITT AND M. JAKOB. *J. Appl. Phys.*, 1951, **22**, 1027.