THE USE OF LAMINAR LUBRICANTS IN COMPACTION PROCESSES

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A punch penetration shear test has been used to support the theory of orientation of layers within the crystal lattice as the lubricating mechanism of laminar solids. Under high applied loads, this orientation is prevented, thereby causing a high value of the shear strength. The increased shear strength is manifest in an increased coefficient of friction under high loads, as found experimentally in the die pressing of solid plugs of talc and graphite. The use of these solids as lubricants in compaction processes cannot be justified at high constraining loads, where the relative density of the compact is high.

TALC has always enjoyed the reputation of being a lubricant in pharmacy, and materials such as graphite and molybdenum disulphide have considerable practical importance as lubricants in many industrial processes. The common property of these materials is that they are laminar solids. Their mechanism of lubrication is frequently attributed to loosely bound lattice layers of the solid sliding easily over each other when placed between moving surfaces[1] (Fig. 1*a*). However, other work[2,3] has also emphasised the importance of the presence of adsorbed materials such as water, ammonia or acetone, since complete degassing produces a material in which the coefficient of friction is extremley high.

Fullam and Savage[4] have shown that by alternating the direction of the moving surfaces a very high frictional coefficient could be obtained. They suggested that when graphite acts as a lubricant, it forms layers

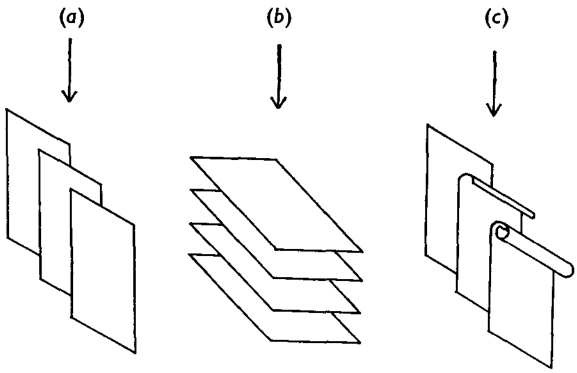

FIG. 1. The mechanism of lubrication of laminar solids.
(*a*) Slip of laminar plates over one another
(*b*) the orientation of plates at 45°, and
(*c*) the "roller bearing" action.

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which are orientated at about 45° to the moving surface. Subsequently, on alteration of the direction of motion, these layers oppose movement until a reorientation within the lattice had been achieved. (Fig. 1*b*.)

Recent work[5] involving the electron microscope has indicated that layers of laminar lubricants roll up in the direction of motion, to form a

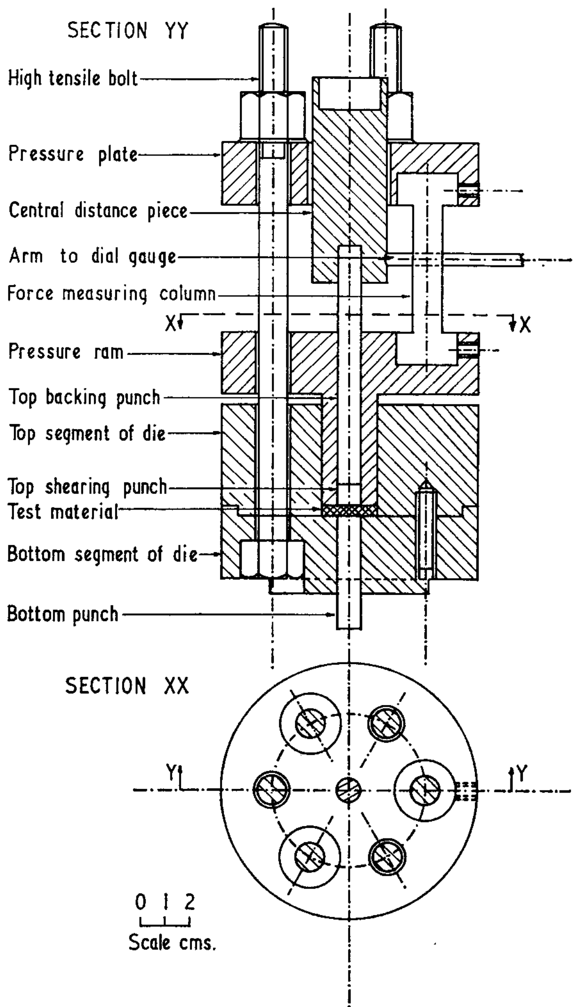

FIG. 2. Shear strength apparatus.

structure which, in the case of graphite, is similar to "whiskers" of the same material[6] (Fig. 1*c*). It is suggested that these rollers could be produced only if there is a loosening, for example, by the presence of water vapour, of the inter-layer binding forces, first at the edges of the crystals and then, later, inside them. This roller mechanism would also explain the high coefficient obtained on alternating the direction of motion of the sliding surfaces. In these circumstances the rollers would have to be unravelled and reformed in the opposite direction.

It is also realised that for the roller mechanism to act efficiently, sufficient space for the roll to form must be available between the sliding surfaces. High pressures, such as are found in the compaction of a tablet mass, would be likely to restrict this mechanism and the purpose

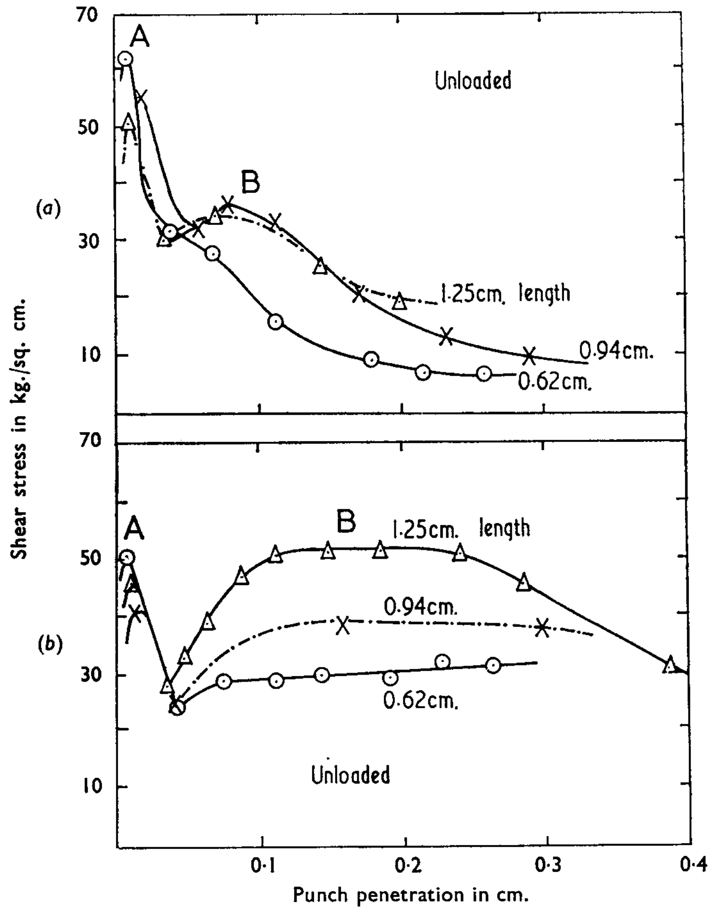

FIG. 3. Shear strength determination of talc. The lengths of plugs are given.
(*a*) In direction normal to the grain
(*b*) in direction parallel with the grain.

of this work was to examine the shear properties of such lubricants for evidence to support this postulate.

APPARATUS

The apparatus used to measure the shear strength of talc and graphite (Fig. 2) operates on a punch penetration principle similar to that used in the blanking process[7]. However, using this apparatus the shear properties of specimens may be measured under high axial loads. The apparatus consisted of a horizontally split die, the upper segment of which has a bore of diameter equal to that of the sample, whilst the lower segment has a bore accommodating only the lower punch. Three

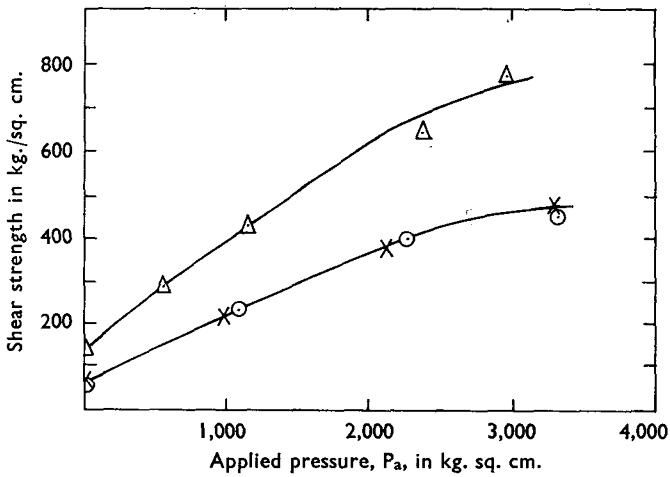

FIG. 4. Effect of applied load on the shear strength of graphite and talc.

△ Graphite.
× Talc (parallel with grain).
⊙ Talc (normal to grain).

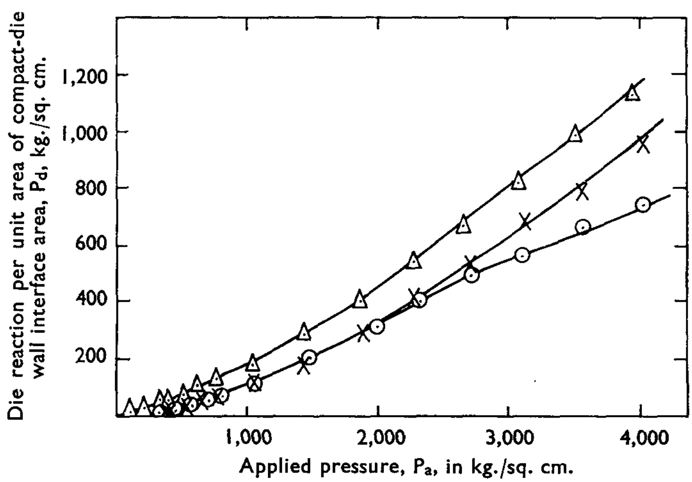

FIG. 5. Die wall friction using solid talc plugs. Die-bore 2·42 cm. diameter.

△ Diameter 2·43 cm., both with and across the direction of the grain.
⊙ Diameter 2·40 cm., across the direction of the grain.
× Diameter 2·30 cm., in the direction of the grain.

high tensile bolts were used to give a force on the pressure plate, which is transmitted, by means of three force measuring columns, to the pressure ram. The apparatus was machined from hardened Al3 steel (Edgar Allen and Co. Ltd.).

The general apparatus and its operation has been previously described by Train and Carrington[8]. The "moving die" technique described by these authors was used throughout. The shear strength apparatus (Fig. 2) replaces the normal punch and die assembly of the die pressing apparatus between the platens of a hydraulic press.

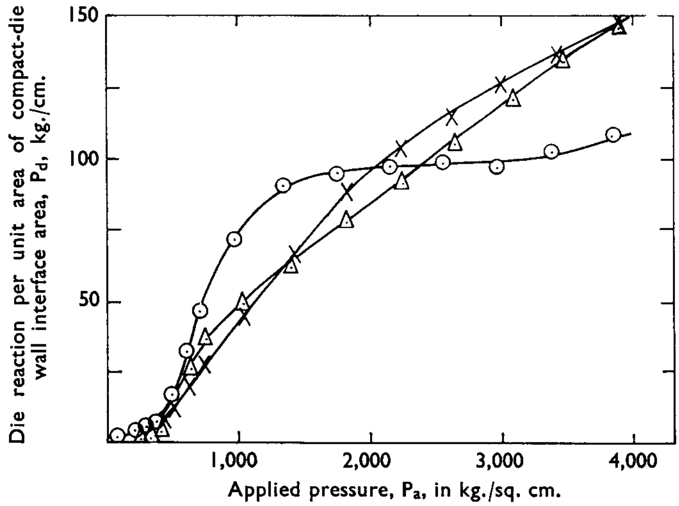

FIG. 6. Die wall friction using lubricated graphite plugs.
× Unlubricated.
△ Lubricated with colloidal graphite.
○ Lubricated with lead foil.

EXPERIMENTAL

The shear strength of graphite (grade EY4A, Morgan Crucibles Ltd.) and of talc, natural crystal, in the directions normal and parallel to the direction of the grain was examined at pre-selected pressures. The samples were degreased using a solution of 50 per cent acetone and 50 per cent carbon tetrachloride. The mechanism of shear used in these experiments is that of forcing an outer ring of the cylindrical sample past a stationary central portion, using a secondary hydraulic ram. The shear forces were measured using the die supporting load cells at increments of punch penetration, indicated by displacement gauges.

The shear strength at zero applied pressure was determined by supporting the bottom punch on a simple helical spring. The pressure ram (Fig. 2) was then adjusted to hold the sample in position without applying a positive compressive load. The assembled apparatus was then placed on the die platform in place of the die-set of the diepressing apparatus, and a force measuring column was used in the shearing punch train.

In the apparatus to measure the shear strength of materials under load, the helical spring was replaced by a hardened A13 steel distance piece. The three high tensile bolts were tightened to a predetermined load over the outer circumference of the specimen, whilst the central punch train was adjusted to an identical pressure over the centre of the sample. The results are presented in Figures 3 and 4. Talc and graphite plugs and powders were also pressed in the die pressing apparatus. The die wall friction of an unlubricated graphite plug was also compared with one lubricated with "Acheson" colloidal graphite and another contained in a wrapping of lead foil. These results are given in Figures 5 to 8.

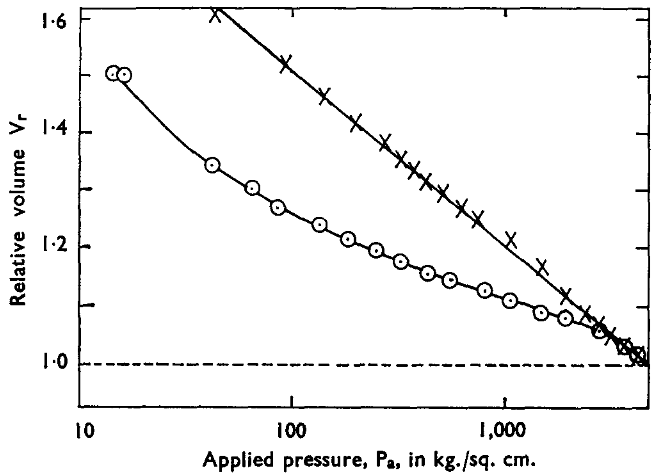

FIG. 7. Consolidation of talc and graphite powders.
× 4·0 g. graphite powder.
⊙ 11·6 g. talc powder.

DISCUSSION

The shear curve of talc (Fig. 3) shows an interesting phenomenon under zero load. As punch penetration proceeds the shear stress is built up until the sample shears at a relatively early extent of punch penetration, A. Subsequent penetration results in a further build up of shear (or frictional) resistance until a second maximum is obtained, B. The phenomenon of a second maximum would appear to be a characteristic of anisotropic solids, and cannot be explained on a simple basis of shear. However, the orientation of layers within the crystal lattice (Fig. 1*b*, or *c*) subsequent to shearing could explain this build up of frictional resistance. Graphite also shows this phenomenon.

Thus, the shear strength of talc given by A shows that the value in the direction of the grain is within 15 per cent of that across the grain. This indicates that a simple shear mechanism does not operate, when it would be expected that the shear strength in the direction of the grain would be much less than that across it.

Figure 4 traces the relationship of the shear strength of talc and graphite against load. The considerable increase of strength of these materials under applied load indicates that the constraining load on the sample prevents orientation within the crystal lattice, resulting in a high shear strength value which is consistent with a high coefficient of friction[1].

A theoretical analysis of the die wall fraction has shown the importance of the shear strength in evaluating the stress distribution within a compact when compressed in a die[9]. The die pressing of talc plugs with a slip fit (Fig. 5, 2·40 cm. dia.) shows that above an applied pressure of approximately 400 kg./cm.^{2} reorientation within the lattice is prevented, having the effect of an increasing die reaction attributed to the increased value of the shear strength.

Plugs injected into the die show (Fig. 5, 2·43 cm. dia.) a gradually increasing die reaction, since under these conditions, the layers cannot

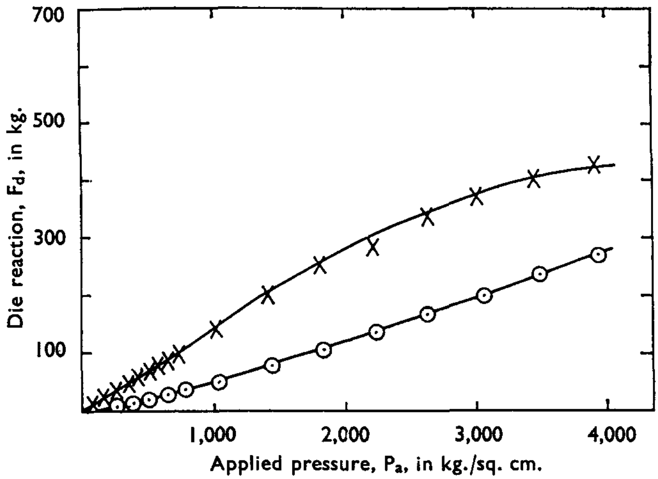

FIG. 8. Die wall friction using talc and graphite powders.
× 4·0 g. graphite powder.
⊙ 11·6 g. talc powder.

reorientate even at low applied axial thrusts as they are constrained by lateral forces. The pressing of graphite plugs wrapped in lead foil (Fig. 6) shows that under high axial loads (above 2,400 kg./cm.^{2}) the lead foil, which shears preferentially compared with the graphite, is the more effective lubricant.

However, with powder systems of talc and graphite the relative volume[10] of the systems is very high (Fig. 7) and decreasing only gradually under compacting forces. Under conditions of high voidage, sufficient space is available for the laminar solid to orientate or form rolls, thereby giving reasonable lubrication. The die reaction observed in the pressing of these powders is correspondingly low.

CONCLUSIONS

The shear strength determination of graphite and talc suggests that the mechanism of lubrication of these solids arises from some orientation within the crystal lattice, probably involving the roller bearing action.

Under high constraining loads, this orientation or rolling up of the layers of the laminar solid is prevented, thereby causing high values for both the shear strength and coefficient of friction.

These materials will act as efficient lubricants only in compaction processes when the voidage of the compact is high. Talc and graphite should not be used as lubricants in the compaction of materials which will deform at low applied pressures to form a solid compact.

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After Dr. Hersey presented the paper there was a DISCUSSION.