

Test Device and Method for Evaluation of Lubricants for P/M Compaction

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Abstract. A critical path to increase mechanical properties, especially fatigue strength, is to increase part density. A logical way to increase part density is to decrease the amount of admixed lubricant, decrease friction losses and compact at elevated temperature. A test device and test method was developed to permit the direct measurement of powder/die friction at temperatures up to 200°C. Commercial and experimental lubricants (admixed and die-wall) were evaluated at several die temperatures and compaction pressures. The effect of die temperature on "stick" and "slide" friction values is used to demonstrate the method's effectiveness.

Introduction. Die-compaction and sintering of metal powders consistently produces net-shape components to close dimensional tolerances at low manufacturing cost. Competitive-pressure and market-forces command the cost reduction of high performance components; a proven way to reduce cost is to reduce or eliminate machining by the use of P/M (powder metallurgy) manufacturing. Designers want to apply this low cost manufacturing method to larger parts that perform at higher stress levels. For high volume production, most P/M parts producers limit punch pressures to 690 MPa (50 tons/in²).

The most effective way to increase mechanical properties is to increase part density. Previous work has demonstrated that consistent achievement of 96% theoretical density will significantly increase fracture toughness and tensile properties of P/M alloy steels⁽¹⁾. High-strength, prealloyed alloy steel powders needed for high performance applications have low compressibility. To attain densities of 7.5 g/cm³, punch pressures greater than 1000 MPa (72.5 tons/in²) are required. This is 45% higher than the punch pressures currently considered "safe" for the production of P/M parts.

The density achieved during the compaction is a function of material properties (flow stress), and the friction forces developed. During compaction under pressure, two basic processes occur: (1) bulk movement of particles, and (2) deformation and fracture of particles. The frictional forces between neighboring particles, and between powder particles and the die, punch and core rod surfaces limit the bulk movement of particles. The movement of particles within the powder mass tends to occur at low

applied pressure. The ease with which this rearrangement process occurs is affected by powder particle shape and surface roughness and the presence or absence of a lubricant.

With regard to the production of high-density components, deformation of individual particles is the major mechanism of densification. As the axial pressure increases, the Poisson effect generates a radial or lateral pressure that acts against the die surfaces. Movement of the powder particles against the die surfaces generates a friction force that opposes the force being applied to densify the powder mass. Lubrication of this interface reduces the friction losses and facilitates the ejection of the compacted part from the die. Without the presence of a lubricant, the dies would score and the friction forces between the die and the as-compacted part may be sufficiently high to preclude ejection of the part from the tooling. The primary method used to provide lubrication has been the addition of micron-sized solid lubricants to the metal powders. Typically, from 0.5 to 1.0 percent of lubricant is added to the powder mix. Methods and lubricants capable of being applied directly to the surfaces of the tooling are being developed and used for some applications. This is termed die-wall lubrication. To evaluate and understand the effect of the lubricant system in the compaction of high-density components a test device and test method was developed to permit the direct measurement of powder/die friction at temperatures up to 300°C.

Test Equipment Design. Roure et al. ⁽²⁾ used the equipment shown in Figure 1 to measure the radial (normal) pressure imposed on the die wall during compaction. They found (see Figure 2) that the average radial stress is constant throughout densification and has a value equal to 0.46 times the compaction pressure. This knowledge allowed them to establish the conditions under which the equipment shown in Figure 3 could be used to directly measure friction coefficients at room temperature.

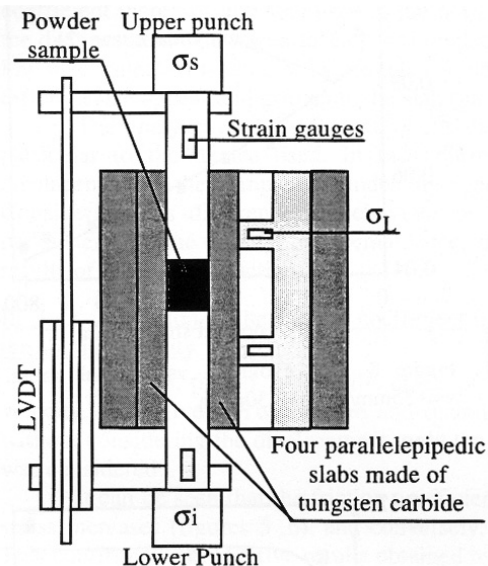


Figure 1. Device for measurement of lateral (normal) stress ⁽³⁾.

Although friction coefficients may be measured with instrumented dies similar to those shown in Figure 1, the device developed by Mosbah et al allows the influence of the normal stress to be separated from the influence of specimen density. In practice, a small volume of powder is compacted directly on the test plate. After pressing to the desired compaction pressure, the load F_a is reduced to 50% of the applied compaction load. A transverse load (F_t) is then applied to the sliding table. Measurement of transverse load and displacement of the slide provide the data needed to calculate static and dynamic friction

coefficients. The test plate allows evaluation of the friction couple between various lubricant systems and various materials used for compaction dies.

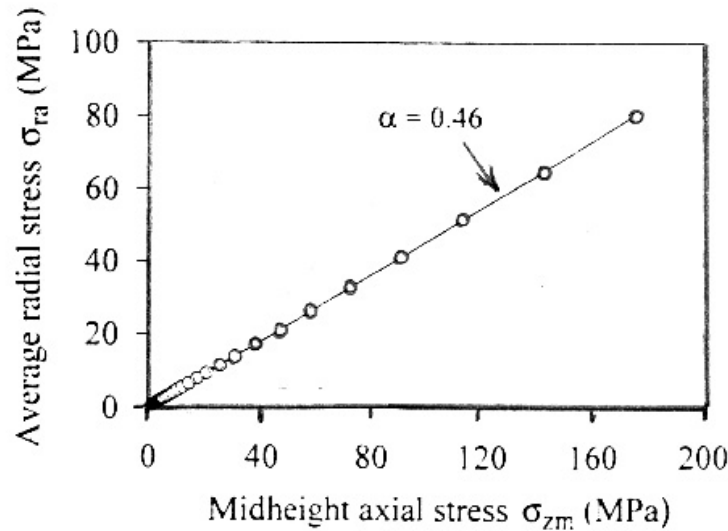


Figure 2. Average radial (normal) stress generated by compaction ⁽²⁾.

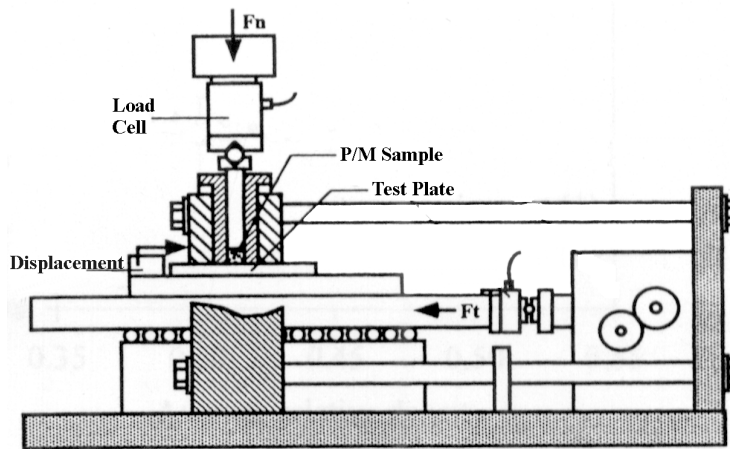


Figure 3. Device used for direct measurement of friction coefficients at room temperature ⁽⁴⁾.

The Caterpillar designed and developed direct friction measurement device (Figure 4) is similar to the device used by Mosbah but has been designed and constructed to operate at temperatures up to 300°C. Heating the die and test plate allows evaluation of lubrication systems, both admixed and die-wall, at temperatures typical of those generated during die compaction of actual components. The heated die assembly is held in a fixed location by a cantilevered support arm. A screw adjuster allows vertical positioning of the die to achieve a 0.05 mm (0.002-inch) clearance between the bottom of the die and the test plate. Thus, there is no friction load between the die and the test plate. The removable test plate and its support structure are also heated. A hydraulic cylinder provides the traverse load. Friction loads are measured with a precision load cell positioned behind the hydraulic cylinder. Slide displacement is also measured and recorded.



Figure 4. Caterpillar direct friction measurement device.

The test device is mounted within the load frame of a 250 KNt (56,000 pound) universal hydraulic testing machine and the ram of the tensile test machine applies the compaction loads. Applied load and displacement are measured with instrumentation common to the test frame. To facilitate attaining compaction pressures of 690 MPa (50 tons/in²) within the load capability of the test machine, the die cavity was sized to a diameter of 16 mm (0.63-inches).

Test Method. Friction measurements are accomplished by compacting a small volume of powder directly on the test plate. Lubricants are added either by admixing with the powder or applied to the test plate (die wall simulation). The test sequence begins by heating both the compaction die and the test plate to the desired test temperature. To minimize the pressure drop caused by die-wall friction and achieve a near homogeneous density distribution in the specimen, only sufficient powder is loaded into the die to achieve a compacted thickness of 3 to 5 mm (0.1 to 0.2-inches). After pressing to the desired compaction pressure, the load is reduced to 50% of the applied compaction load (simulates the normal stress applied to die wall during compaction). A transverse load is then applied to the sliding table. Transverse load and displacement data are recorded for analysis. A typical friction load curve is shown in Figure 5. The indicated maximum corresponds to the load required to overcome the static friction between the compacted specimen and the test plate. With continued movement of the test plate the friction load drops rapidly, levels off and then rises again as the lubricant film between the specimen and the test plate is depleted.

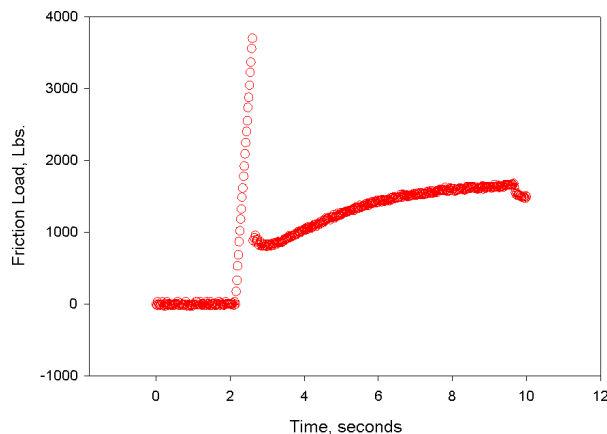


Figure 5. Typical curve for direct measurement of friction loads.

Discussion. Several commercial and experimental lubricants were evaluated at test temperatures ranging from 66°C (150°F) to 232°C (450°F). The lower temperatures are representative of those generated during conventional compaction of some large parts. Temperatures equal or greater than 150°C (300°F) would be typical of those that could be used for warm compaction. For illustrative purposes, the measured friction loads were converted into relative values; i.e., the value obtained for a particular test condition was divided by the friction load values measured for a baseline condition. Our baseline condition is 0.75% Acrawax admixed with a steel powder, compacted at 690 MPa (50 tons/in²), and tested at a temperature of 66°C (150°F). The result of the experiment was the same as that of the baseline if the relative performance has a value of 1.0. Lower values indicate lower friction loads (higher performance) and higher values indicate higher friction loads or reduced performance.

The experimental results generally showed that increasing test plate (die) temperature increased sticking friction loads (Figure 6) but had less effect on sliding friction loads (Figure 7). At a test temperature of 93°C (200°F), the Kenolube is liquid and outperforms the other two admixed lubricants. This does however leave a lubricant film on the die that may flake off and create defects in the as-pressed parts.

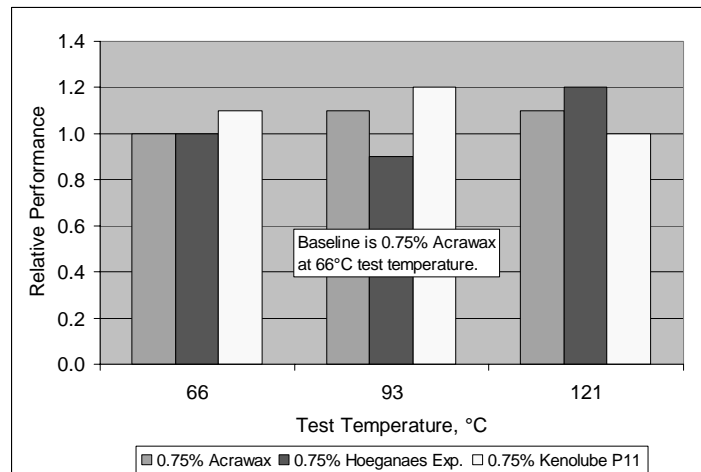


Figure 6. Effect of test temperature on sticking friction performance of 0.75% admixed lubricant.

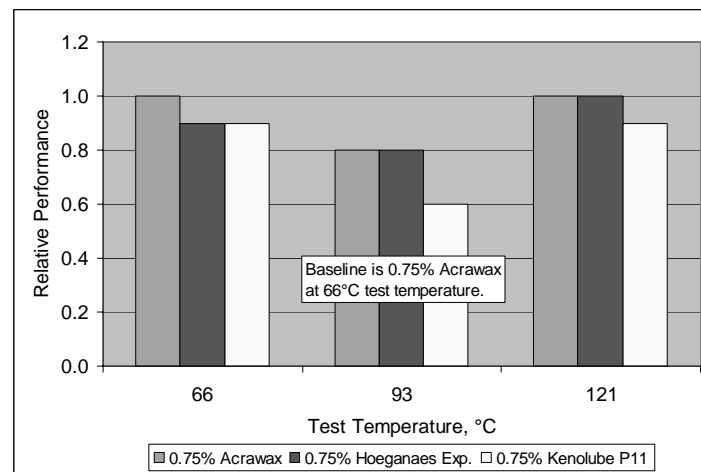


Figure 7. Effect of test temperature on sliding friction performance of 0.75% admixed lubricant.

The effectiveness of die-wall lubrication is dramatically illustrated in Figure 8. The powder used for these experiments contained no admixed lubricant. Yet, with one exception, the overall performance of the lubricant system was dramatically increased. Although, Kenolube was effective in reducing sliding friction loads, its use is problematic at temperatures above 80°C (175°F) because of the lubricant film left on the test plate (die). Only one data point is shown for the graphite die-wall lubricant because its solvent is water and can't be used at test (die) temperatures below 100°C (212°F).

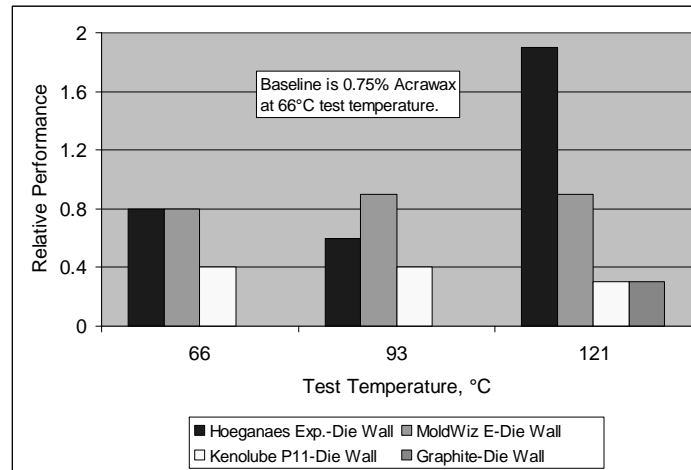


Figure 8. Effect of die-wall lubrication on static friction performance.

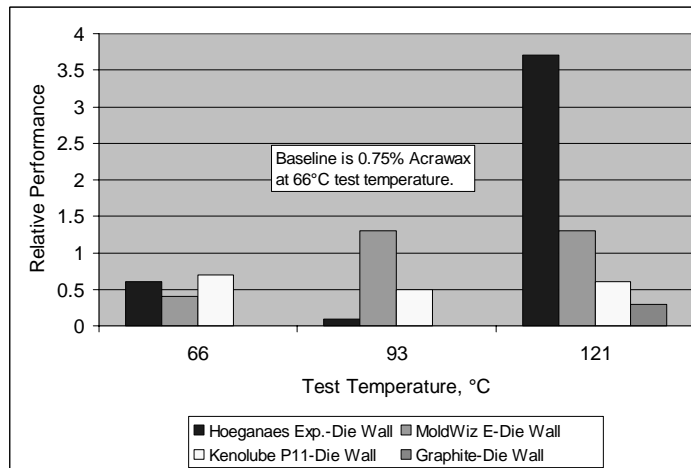


Figure 9. Effect of die-wall friction on sliding friction.

Conclusions:

1. A test device was developed and successfully used to directly measure static and sliding friction loads at temperatures up to 232°C (450°F).
2. The use of lubricants at temperatures above their melting temperatures may reduce friction loads but leave a residue on the compaction die. This may lead to other production problems.
3. Lubricant systems (lubricant and die steel) should be evaluated at their intended use temperature because of the negative effect of temperature on both static and dynamic friction coefficients.

References:

1. G. A. Gegel, P. Kurath and K. Boswell, "Low Cost Fracture Toughness Testing of P/M Materials", V. 4, *Advances in Powder Metallurgy and Particulate Materials-1996, 1997*, Metal Powder Industries Federation, Princeton, NJ, p. 13-329.
2. Roure, S., Bouvard, D. Doremus, P, Pavier, E., "Analysis of die compaction of tungsten carbide and cobalt powder mixtures", *Powder Metallurgy*, 1999, vol. 42, no. 2, p 164.
3. Pavier, D., Doremus, P., "Friction behaviour of an iron powder investigated with two different apparatus", *Proceedings International Workshop on Modeling of Metal Powder Forming Processes*, Institut National Polytechnique de Grenoble, Grenoble, France, 1997, p. 335.
4. Mosbah, P., Bouvard, D., Ouedraogo, E., Stutz, P., "Experimental techniques for analysis of die pressing and ejection of metal powder", *Powder Metallurgy*, 1997, vol. 40, no. 4, p 269.