International Journal of Scientific World, *10 (2) (2024) 24-28*

International Journal of Scientific World

Website: www.sciencepubco.com/index.php/IJSW

Review paper

Exploring the reuse of cooking and motor oils in cold forging processes

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Abstract

In contemporary industrial practices, the pursuit of sustainable manufacturing processes is imperative. Cold forging of aluminum, a versatile and widely used metal, relies heavily on lubrication to reduce friction and wear during deformation. Conventional lubricants, such as mineral oils, raise environmental concerns. Nevertheless, oils are common and essential products for manufacturing utensils in various sectors such as metallurgy, culinary, and automotive, among others. This study evaluates the lubrication performance of used cooking oil and old motor oil in aluminum cold forging, examining the surface finish, roughness, and compression test (tension vs deformation chart) flow, maximum deformation. Results indicate positive lubrication effects, with cooking oil showing the best performance when combined with graphite. Statistical analysis confirms significant differences in lubricant performance compared to dry forging. Visual inspection reveals smoother surface markings with lubricants, particularly cooking oil. Uniaxial compression tests demonstrate improved mechanical behavior with lubricants, especially when combined with graphite. Overall, lubricants enhance surface finish and mechanical properties, underscoring their potential for sustainable forging practices. The use of recycled oils like used cooking oil and old motor oil can contribute to a more environmentally friendly manufacturing process.

Keywords: *Lubricants. Forging. Reuse.*

1. Introduction

In contemporary industrial practices, the pursuit of sustainable and environmentally conscious manufacturing processes has become increasingly imperative. This necessitates a delicate balance between maintaining productivity, ensuring product quality, and minimizing adverse environmental impacts [1]. Metal forging stands as a cornerstone of metal component production, owing to its efficiency, material properties, and minimal material waste. Central to the success of the forging process is lubrication, which plays a critical role in reducing friction and wear between the workpiece and dies. [2]

Aluminum is a lightweight and versatile metal known for its corrosion resistance and high strength-to-weight ratio. Its properties make it ideal for a variety of industrial applications, including aerospace, automotive, construction, and packaging. Additionally, aluminum is easily formable and can be cold or hot-forged to produce parts with dimensional accuracy and mechanical strength [3].

In the cold forging process of aluminum, the metal is plastically deformed at room temperature or slightly above it, without the need for preheating. This results in parts with superior mechanical characteristics, such as strength and toughness, as well as a high-quality surface finish. Cold forging is widely used in the manufacturing of precision components such as screws, pins, shafts, and gear parts, contributing to the efficiency and reliability of a variety of industrial products. However, in the cold forging process, the role of lubricants is critical, since the mechanical efforts and friction are severe [4], [5].

The use of lubricants in metal forming operations has been categorized into various types, including water-based, oil-based, synthetic-based, and solid-based lubricants. However, concerns regarding environmental pollution and health hazards associated with conventional lubricants have spurred the exploration of alternative lubrication strategies. In this context, vegetable oils have emerged as promising candidates due to their biodegradable, non-toxic, and renewable properties. They offer comparable lubricity to mineral-based oils, along with other desirable characteristics such as a high viscosity index and low volatility, at a lower cost [1], [2], [6], [7].

Efforts to enhance the lubrication performance of vegetable oils have led to the exploration of chemical and thermal modifications, as well as the incorporation of oil additives. While nanoparticle additives have shown promise in improving the tribological properties of lubricants, this study focuses on the reuse of cooking and motor oils, specifically emphasizing their potential as environmentally friendly alternatives in metal forging processes [8].

Previous studies have highlighted the efficacy of vegetable oils in providing stable boundary lubrication conditions and improving lubrication efficiency in machining processes. Yet, further research is needed to ensure their viability as alternative lubricants in forging processes. Challenges such as lower thermal and oxidation stability, limited viscosity range, and compatibility with conventional oil additives need to be addressed to fully exploit the potential of vegetable oils in metal forging [9].

In light of these considerations, this study aims to assess the lubrication performance of used cooking oil and old motor oil in cold forging processes with aluminum, focusing on the generated surface finish and their combinations with graphite. The findings of this study are expected to provide valuable insights into the behavior of cooking and motor oils in cold forging processes, particularly with aluminum. By examining their impact on surface finish and tribological characteristics, this research aims to contribute to the development of sustainable and eco-friendly manufacturing practices in the forging industry. Additionally, the results will inform decision-making regarding lubricant selection, which has implications for industries across various sectors, including metallurgy, culinary, automotive, and beyond.

2. Materials and methods

The experimental procedure was performed in the Materials and Metallurgy Laboratory of the Federal Institute of Mato Grosso do Sul in Corumbá/Brazil. The methods were summarized in the flowsheet displayed in Figure 1.

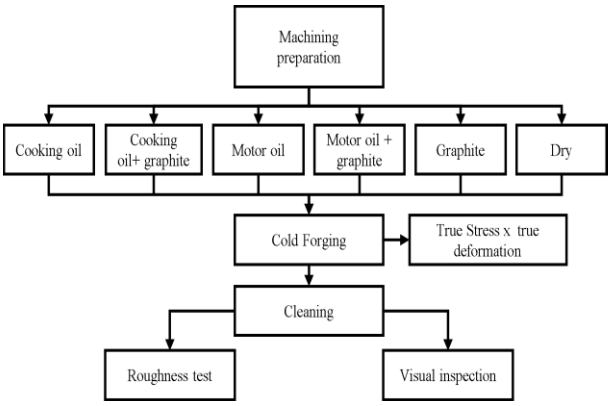

Fig. 1: Flowsheet of the Experimental Procedure.

2.1. Machining preparation

A 6351-aluminum bar, with chemical composition supplied by the local market, shown in Table 1, was used with a diameter of 1/2 inch as the material for cold forging. This bar underwent transverse cuts to adjust its height to 23.3 mm (for a D/h ratio of approximately 0.5). This process was carried out by a lathe to ensure the parallelism of the surfaces. After the cuts, the samples did not undergo any surface preparation (such as sanding). This material preparation is a key step in the cold forging process.

Table 1: Chemical Composition of Steel Obtained from Supplier

Si(wt%)	Mg	Fe	Mn	Cr	Zn	Ti	Al
0.60	0.80	0.55	0.10	0.15	0.2	0.1	balance

2.2. Cold forging

Cold forging was carried out on an EMIC universal mechanical testing machine (Figure 2) with a capacity of 300 kN with 2 mm/min of displacement speed. Before each test, both the samples and the die were cleaned with isopropyl alcohol. Then, lubricants were applied using a brush. Two test end parameters were established: a maximum load of 200 kN or 20 mm displacement. After the tests, photographic records of the samples were taken.

Fig. 2: EMIC 300kn Universal Mechanical Testing Machine.

The final height results (measured manually) are shown as means values, and the standard deviations are indicated by error bars. Additionally, analysis of variance (ANOVA) was performed to detect statistical significance and potential synergistic effects among the studied input parameters. Significant differences were distinguished using Duncan's test with significance set at $p \leq 0.05$.

2.3. Roughness measurements

Surface roughness measurements were conducted both before and after the cold forging using a Rugosimeter 400 TR.200 DIGIMESS, as Figure 3 represents.

Fig. 3: Rugosimeter 400 Tr.200 Digimess.

Initially, the surface of each sample was cleaned using paper towels and alcohol. Subsequently, the equipment was assembled and calibrated to the precise height of the specimen, with the aid of an accompanying acrylic plate. Securing the sample in place was achieved using a precision clamp.
Prior to experimentation, baseline roughness measurements were conducted using a sample unaffected by the forging process, retaining only the surface finish imparted by machining.
Following the apparatus setup, the roughness sensor was accurately positioned at the initiation point of the designated section (Figure 4) for measurement.

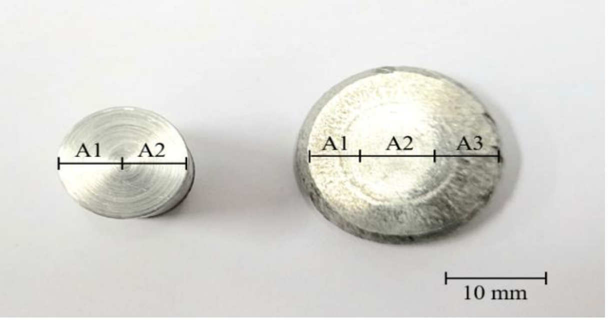

Fig. 4: Regions for Measuring Sample Roughness (A) Machined Specimen (Pre-Forging); (B) Forged Specimen).

The roughness tester operated with measurements in the micrometer (µm) magnitude and according to the following parameters:
LTH (Cut-off): 0.80mm;
STD (Regulatory standard): ISO;
FIL (Filter): RC;
RAN (Measurement range configuration mode): ±80µm.
The results are shown as means values, and the standard deviations are indicated by error bars. ANOVA was performed, and significant differences were distinguished using Duncan's test with significance set at $p \leq 0.05$.

3. Results and discussion

Figure 5 shows the final height of forging tests, and it is possible to notice that the alternative lubricants exhibit positive performance. During the forging process, they effectively fulfill their primary function: reducing the coefficient of friction. This reduction in friction coefficient leads to increased deformation by facilitating material flow. This effect is clearly observed when comparing the smallest final length obtained from a dry-forged sample with the longest final length achieved by a sample forged with the application of one of the oils. The difference in final length amounts to 1.24 mm.
Examining each test batch individually, it is noteworthy that samples forged using cooking oil as a lubricant exhibited greater deformation, resulting in the smallest final lengths among the six groups. The ANOVA confirmed the significant difference in performance among all tested lubricants compared to the dry test ($p=7.2x10^{-7}$). Conversely, the least deformation, on average, occurred in samples forged with the application of motor oil as a lubricant. However, although some differences were observed in the final heights of the tests, after Duncan's test, no significant differences were detected among the tested lubricants. This places cooking oil on par with motor oil, a lubricant widely recognized for its excellent lubricating properties. Moreover, the addition of graphite to the system did not result in a statistically significant synergistic effect.

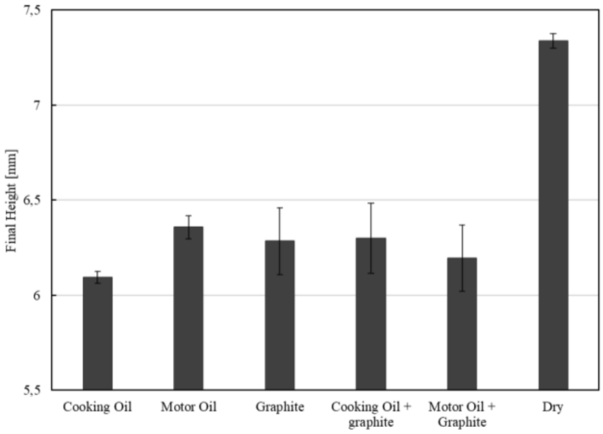

Fig. 5: The Final Height of Forging Tests in All Studied Systems.

Figure 6 illustrates images derived from the visual inspection conducted subsequent to the cold forging trials. Within Figure 6(a), representative of the dry test, fractures exhibiting 45° angles are evident, characteristic of compression-induced failure. This suggests that the material encountered a region of constrained flow internally, leading to collapse, likely attributable to elevated friction, resulting in the matrix surface "capturing" the specimen, thereby impeding its movement. Conversely, across all other trials (Figures 6 b-f), this phenomenon is absent. The material demonstrated plastic flow throughout the entirety of the assessment. Consequently, the inclusion of alternative lubricants prevented fracture due to compression.

One can also discern smoother markings along the peripheries and more striated patterns at the center of all samples. Evidently, these "striated" regions delineate the original surface of the sample, characterized by a machined finish, which was partially retained, whereas the peripheral areas stem from the lateral surface of the cylinder subjected to compression, thus yielding a comparatively smoother visual appearance in this locale.

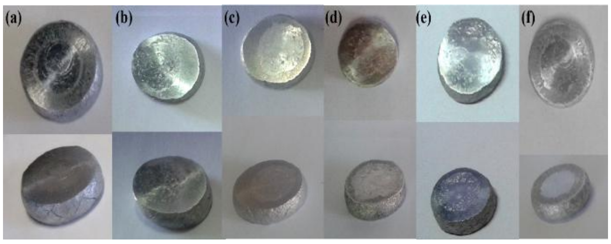

Fig. 6: Visual Inspection of Samples. (A) Dry, (B) Graphite, (C) Motor Oil + Graphite, (D) Cooking Oil + Graphite (E) Motor Oil (F) Cooking Oil.

Figure 7 presents the results of a uniaxial compression test conducted on an aluminum sample. During the test, different lubricants were applied to the sample to assess their impact on the material's mechanical behavior. Five systems were tested: Dry, Graphite, Motor Oil, Motor Oil + Graphite, and Cocking Oil + Graphite.

Initially, the Dry system exhibited the highest flow stress, indicating greater resistance to deformation. However, it was surpassed by both motor oil combinations and cocking oil-lubricated systems. It is noted that any combination containing motor oil showed results very close to the dry system. However, the lubricated system with solid graphite exhibited lower stress throughout the test. As for cooking oil, it presented a very similar result to the dry system but performed the best out of all tested systems when combined with graphite.

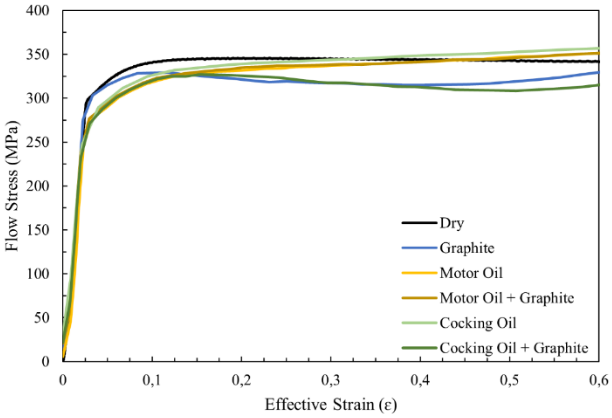

Fig 7: Flow Stress Versus Effective Strain of All Tested Parameters.

The observed "fall" of the tension in pure graphite systems and cooking oil + graphite is most likely due to sample shear effects This supports the better performance of these lubricants, as this effect is more likely to occur in systems exposed to lower friction coefficients. Another important observation is that the only system that suffered a fracture was the dry system In Figure 6(a), a 45° fracture is evident, typical of failure due to compression. Thus, it can be affirmed that all tested lubricants have advantages in terms of sample integrity, as they only deformed but did not fracture.

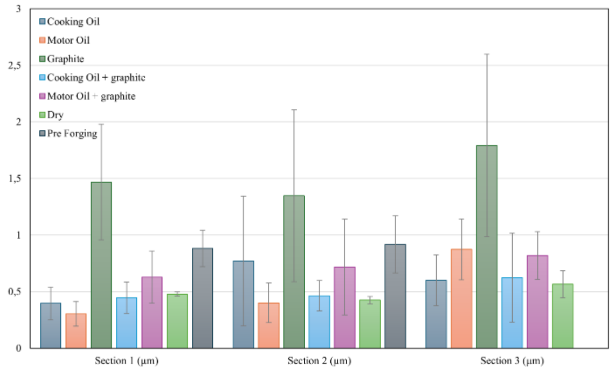

Fig. 8: Roughness and Standard Deviation of All Tests Performed in Sections 1, 2, and 3.

Figure 8 illustrates the roughness outcomes of the samples subsequent to the forging assessments, across the three sections of the component. Upon scrutinizing the three sections within each system, it becomes apparent that while visual inspection reveals a disparity in appearance between the central and peripheral regions (Figure 6), no statistically significant disparities in sample roughness are discerned ($p>0.05$ for all conditions). However, if one considers all measurements of sections 1, 2, and 3, there is a significant difference between the lubrication conditions on the roughness ($p=4.28x10^{-4}$). After Ducan's test, one can conclude that the use of graphite has resulted in a significantly higher roughness than by using other lubricants, except when compared with the pre-forging condition. This phenomenon may be attributed to graphite's solid lubricant nature, which could induce surface deformation, consequently augmenting the material's surface roughness. Nevertheless, there is no significant difference between the roughness when using the other lubricants. Indeed, if one observes the high standard deviation of measurements in Figure 8, it becomes evident once more that these disparities lack statistical significance.

4. Conclusion

In conclusion, the research findings underscore the efficacy of cooking oil as a lubricant, demonstrating its ability to enhance surface finish and flow, while the combination of motor oil and graphite yielded notable deformation. These discoveries hold significant implications for sustainable industrial practices, showcasing the potential to minimize environmental impact through the reuse of discarded oils without compromising product quality. Moreover, the emergence of cooking oil as a viable alternative to conventional lubricants underscores its comparable performance in surface finish and deformation capabilities.

These insights have far-reaching implications across industries, from metallurgy to automotive, emphasizing the importance of exploring eco-friendly lubrication solutions for more sustainable manufacturing practices. Thus, the integration of cooking and motor oils as lubricants in cold forging processes not only offers a practical alternative but also represents an environmentally friendly strategy, charting a promising course for the forging industry.

Acknowledgement

This work was supported by the Federal Institute of Science and Technology of Mato Grosso do Sul.

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