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Investigation of the Performance of Vegetable Lubricants in Cold Pressing

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Abstract **–**Cold pressing is a plastic shaping method used for materials to gain superior mechanical properties. In this shaping method, surface quality is of utmost importance. Lubricant surface quality is one of the highly effective parameters in achieving the desired surface quality in the pressing process. Recently, considering sustainability and human health, vegetable-based lubricants have come to the forefront and are open to further development. In this study, the performances of vegetable-based lubricants in cold pressing were evaluated by determining and assessing the roughness transfer ratios from the press tool to the sheet material. Vegetable-based lubricants such as sunflower oil, soybean oil, canola oil, and palm oil were compared with motor oil for the purpose of comparison and were evaluated under dry conditions. The conditions where motor oil was used as the lubricant showed the lowest roughness transfer ratio of 73%, indicating the best performance. Palm oil followed with a roughness transfer ratio of 76%, sunflower oil with 78%, soybean oil with 79%, and finally, canola oil with 82%. Among the four different vegetable-based lubricants used in the study, palm oil exhibited the highest performance, while canola oil had the lowest performance. Although the lubrication performance of vegetable-based lubricants is weaker compared to synthetic-based lubricants, it was concluded that they have potential for improvement and can be used as lubricants by addressing their weaknesses in the manufacturing processes.

Keywords – Metal Forming, Roughness Transfer, Vegetable Oils, Green Lubricant, Surface Roughness

I. INTRODUCTION

Cold pressing is a plastic pressing process used to produce parts with enhanced mechanical properties. Surface quality is particularly important in the production of these parts. The surface quality of the produced parts is influenced by various parameters such as initial surface roughness, relative sliding velocity, temperature at the contact area, sliding distance, contact normal stresses, and lubrication used [1]. Among these parameters, lubrication plays a crucial role. Insufficient lubrication or breakdown of lubricating films promotes direct contact between the workpiece and the mold, leading to mold damage due to increased friction and deformation loads [2]. Additionally, lubrication conditions are important parameters that affect the surface quality of the produced parts [3]. Surface quality plays a significant role in the adhesion of paint or coatings to the material surface [4, 5]. Furthermore, the roughness of the material surface affects its resistance to corrosion depending on the working conditions [6].

Several lubricants have been developed for metal pressing processes. In the pressing process, low-viscosity mineral oils, synthetic oils, or water-based lubricants are used. Additionally, in cold pressing, the lubricant can be an extrusion oil or a soap [7]. Rao and Xie conducted a comparative analysis of boric acid, PTFE (polytetrafluoroethylene), and graphite lubricants in the cold pressing of aluminum, brass, and steel. They found that boric acid performed better than the other lubricants [8]. Ngaile et al. stated that two soap-based lubricants, calcium and sodium, performed at the same level as the traditionally used zinc-based soap lubricant [9]. Rao et al. demonstrated in their study that dry lubricants such as boric acid and PTFE performed well, comparable to grease and graphite lubricants. There is a limited literature on the use of vegetable-based lubricants in cold pressing processes [10].

The global trend towards using lubricants that are safe for health and the environment presents challenges for traditional lubricants. Commonly used lubricants are often flammable and contain active elements such as chlorine, sulphur, and phosphorus, which can potentially be hazardous. The difficulty and cost of disposing of these lubricants necessitate the development of more suitable and renewable lubricants [11]. However, in the case of cold pressing, lubricants are generally of the traditional type, and there is a lack of studies in the literature regarding renewable (bio-based) lubricants. Therefore, this research has been conducted to provide alternatives to address these disadvantages and fill the gap in the literature.

In this study, surface roughness transfer was carried out from a tool with a lower arithmetic mean roughness (R_a) value to a sheet material with a higher R_a value in cold pressing. Vegetable-based (bio-based) lubricants such as sunflower oil, soybean oil, canola oil, and palm oil were used as lubricants, and motor oil was used for comparison purposes. The performances of the vegetable-based lubricants were evaluated by comparing the roughness transfer ratios from the tool surface to the sheet material.

II. MATERIALS AND METHOD

A. *Materials*

The study utilized DC04 grade soft steel sheet materials suitable for cold pressing. The chemical composition and mechanical properties of this material are documented in a previous study [12]. The sheet material samples used in the pressing process were cut from 1 mm thick material into dimensions of 10 mm × 10 mm. Their surfaces were cleaned with acetone to prepare them for the pressing process. The pressing tool used in cold pressing was made of 2767 tool steel and had a diameter of 12 mm and a length of 8 mm. The tool surface was sanded using 600 and 2000 grit water sandpapers to achieve minimum roughness. Vegetable-based lubricants commonly used in metal pressing include palm oil, soybean oil, canola oil, and sunflower oil [13]. Accordingly, sunflower oil, soybean oil, canola oil, and palm oil were used as vegetable-based lubricants in the pressing process, along with motor oil for comparison purposes. These lubricants were sourced from the market.

B. *Methods*

The pressing process was carried out on a column hydraulic press. The schematic diagram of the pressing setup is shown in Figure 1. The applied load on the materials was measured using a pressure gauge and maintained for a duration of 40 seconds. The maximum load of the hydraulic press and the pressure monitoring curve from the pressure gauge indicated that approximately 6250 kg of load was applied to the material. The lubricant used in the pressing operation was applied at a rate of 0.5 ml on the interface. To prevent complex interactions between lubricants, the press tool and table surface were cleaned with alcohol after each pressing operation. These lubricants were sourced from the market.

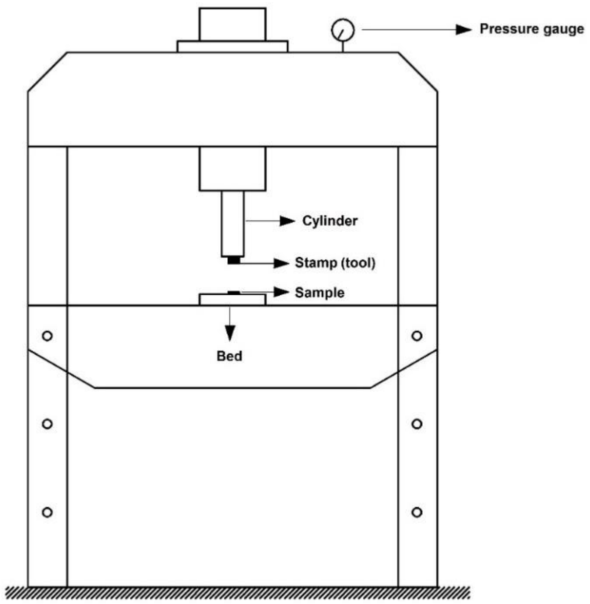

Fig. 1 Schematic pressing mechanism

The surface roughness measurements were determined using the PCE-RT2000 roughness meter. Prior to the measurements, the surfaces were cleaned with acetone to remove any potential residues. The measurements were taken on the stamp surface and the sheet material surfaces before and after the pressing operation. The roughness measurements were repeated at three different points on the surfaces, and the average of these measurements was taken to determine the arithmetic mean roughness (R_a) parameter. Figure 2 illustrates a schematic representation of the roughness measurements [14].

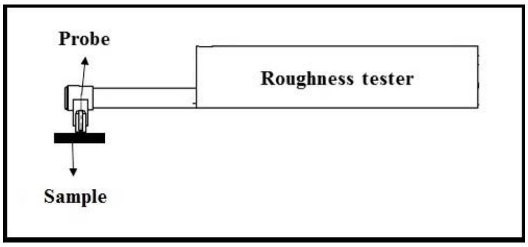

Fig. 2 Schematic picture of roughness measurements [14]

The amount of deformation (r) occurring in the sheet material was calculated by measuring the thicknesses of the material before and after pressing using a precision micrometer, with the help of Equation 1 [15]. In Equation 1, r_0 represents the initial thickness of the sheet material, and r_1 represents the final thickness of the sheet material after pressing. Additionally, the roughness transfer ratio (R) was determined using Equation 2 [16]. In Equation 2, S_0 represents the roughness of the sheet material before pressing, S_1 represents the roughness of the sheet material after pressing, and S_t represents the roughness of the tool (stamp).

$$r\ (\%) = \frac{r_0 - r_1}{r_0} \quad (1)$$

$$R\ (\%) = \frac{S_1 - S_0}{S_t - S_0} \quad (2)$$

III. RESULTS AND DISCUSSION

The amounts of deformation occurring on the sheet materials as a result of the cold pressing process were determined using Equation 1, and it was found that the deformation amount was approximately 4.5±0.3% on average. Table 1 provides the experimental design and the measured R_a (arithmetic mean roughness) roughness parameter values. The average R_a roughness parameter value of the sheet material before the cold pressing process was 1.226 µm. Similarly, the average R_a roughness value of the tool (stamp) was measured to be 0.153 µm.

Table 1. Experimental design and measured R_a roughness parameters

Experiment	**Measured roughness values (R_a)**			**R_a (mean)**
Dry	0.247	0.286	0.418	0.317
Sunflower oil	0.336	0.480	0.355	0.390
Engine oil	0.507	0.369	0.459	0.445
Soybean oil	0.330	0.318	0.483	0.377
Canola oil	0.287	0.403	0.357	0.349
Palm oil	0.402	0.381	0.456	0.413

Figure 3 illustrates the roughness transfer ratios from the tool to the surface of the sheet material in cold pressing using different types of lubricants under dry conditions. In dry conditions, approximately 85% of the roughness was transferred from the tool to the surface, indicating that most of the roughness was transferred to the sheet material surface. The conditions with the lowest roughness transfer ratio were when motor oil was used as the lubricant, with a roughness transfer ratio of approximately 73%. Evaluating the roughness transfer ratio of this lubricant suggests that it hinders roughness transfer compared to dry conditions. Therefore, it can be said that the lubricant with the highest performance among those used in the study is motor oil. This indicates that motor oil provides better lubrication performance and effectively prevents friction in transferring roughness compared to vegetable-based lubricants. The applied load on the sheet material samples was approximately 6 kN per unit length. In a study conducted in the literature, the roughness transfer ratio from a tool with coarse roughness to the material was found to be around 85% under the influence of a 5 kN/mm load and in dry conditions. It was also observed that the roughness transfer ratio was approximately 60% under lubricated conditions [17]. Therefore, in this study, the applied load on the material is approximately 6 kN/mm, which yields results consistent with the literature. When evaluating the roughness transfer ratios to the surface of the sheet material, motor oil is followed by palm oil at 76%, sunflower oil at 78%, soybean oil at 79%, and finally, canola oil at 82%. Among the four different vegetable-based lubricants used in the study, palm oil exhibits the highest performance. It is also notable that among these lubricants, canola oil has the lowest lubrication performance according to the roughness transfer ratios. This observation is believed to be highly correlated with the viscosities of the lubricants and their lubrication behavior under load. Although vegetable-based lubricants do not exhibit as high performance as motor oil, their affordability and eco-friendliness make them suitable alternatives. Improving the weak aspects of vegetable-based lubricants, such as their oxidation and hydrolytic stability, will make them more desirable.

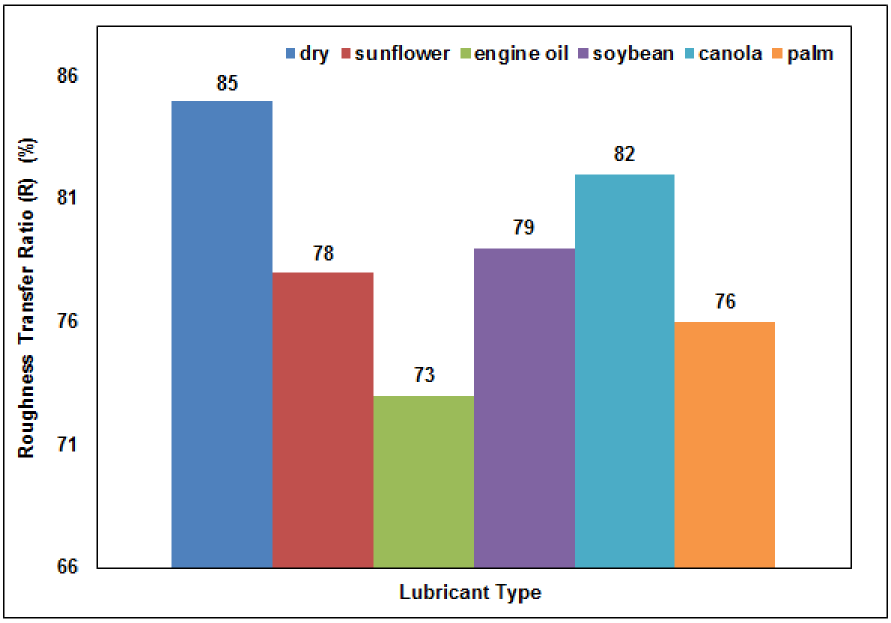

Fig. 3 Roughness transfer rates transferred to the material surface under dry condition and cold pressing with different lubricants

IV. CONCLUSION

In this study, the performances of vegetable-based lubricants in cold pressing were evaluated by determining and assessing the roughness transfer ratios from the tool with a lower average roughness (R_a) value to the sheet material with a higher R_a value. Vegetable-based lubricants such as sunflower oil, soybean oil, canola oil, and palm oil were used as lubricants, with motor oil used for comparison, and compared under dry conditions. The results obtained from the study are as follows.

- It was observed that vegetable-based lubricants had a higher roughness transfer ratio compared to synthetic motor oil in cold pressing, indicating that motor oil performed the best.
- Among the vegetable-based lubricants, palm oil showed the best performance with the lowest roughness transfer ratio, followed by sunflower oil and soybean oil. Canola oil exhibited the lowest performance among the vegetable-based lubricants.
- Although the lubrication performance of vegetable-based lubricants was weaker compared to synthetic lubricants, it was concluded that they have potential for improvement and can be used as lubricants in manufacturing processes by addressing their weak points.

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