Effect of Burnishing Tool Radius and Coolant Technique on Burnishing Performance

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Abstract. Burnishing is an essential technique to enhance a quality of surface finish and dimensional accuracy. This process produces higher friction on the workpiece surface thus accelerate the burnishing wear rate. Therefore, a coolant need to be introduced in this process. In this study, various coolant strategies were implemented to investigate their performance on burnishing process. Burnishing tool made from carbide with two corner radius sizes namely R1 and R2 were used in this study. It was observed that burnishing tool of R1 outperformed R2 in terms of thrust force, temperature and surface roughness. In addition, SCCO$_2$ + MQL exhibited superior performance compared to MQL and dry strategies.

1. Introduction

Burnishing process requires no material removal process that modifies the integrity of machined surface by severe plastic deformation. As a consequences, it enhances the hardness of surface and shorter polishing period. Burnishing process is considered as a cold working process, produces a smooth and work-hardened surface by plastic deformation of surface irregularities. It improves dimensional accuracy, surface finish and shape of the machined components.

According to the study conducted by Revankar et al. [1], they observed that the surface roughness decreases by using moderate range of forces from 150 to 200 N. However, the value of surface roughness increases at the higher range of force from 200–300 N. This phenomena is attributed to the burnishing ball slightly penetrates into a work surface, thus contributes to incomplete deformation of the asperities, subsequently reduces the surface roughness. The formation of surface roughness was enhanced as the force increases. It is due to the protrusion of work in front of the burnishing tool becomes large and the plastic deformation region broadens.

Low and Wong [2] stated that the roughness of polymer surfaces can be improved by using low burnishing force of 60 N. However, the higher burnishing force up to 124 N outperformed the lower force of 60 N in terms of improvement of surface roughness. They hypothesized that the penetration of the ball inside the surface became deeper at high burnishing force, and consequently increasing the amount of asperities being deformed. El-Khabeeery and El-Axir [3] have conducted a study on the effect
of number of burnishing passes. They found that multiple passes of burnishing process produces severe
damage of surfaces. It is mainly attributed to the over hardening and consequently flaking of the surface
layers, especially at higher rotational speed. The surface finish can be improved by combining the
multiple passes with low feed rate. This condition is able to enhance the surface structural homogeneity
resulting in an increase in the surface finish.

There are many cooling techniques were introduced to reduce the machining temperature, such as flood
and minimal quantity lubrication (MQL). Flood coolant technique is considered as a harmful if using a
mineral based lubricant. Alternatively, MQL is preferred due to the low consumption of lubricant with
a combination of hazardous free lubricant [4,5]. Recently, the application of cryogenic coolant has been
introduced to the industry, which is more sustainable and significantly improving the machining
performance [6,7,8,9]. However, this technique has not been proven in terms of its performance for
burnishing process. Therefore, in this study is to evaluate the burnishing performance by comparing
different cooling techniques in term of burnishing force, temperature and surface roughness.

2. Experimental Setup

The workpiece material with grade SS400 carbon steel was undergoing burnishing process. It was
conducted on the MAZAK Nexus 410A-A CNC vertical machining center. The workpiece was
mounted on the piezoelectric force sensor dynamometer (Kistler Dynamometer 9254) as shown in
figure 1. Multichannel amplifier 5070A transferred and translated the signals from the
dynamometer. In this study, Frictional Stir Burnishing tool was used as shown in figure 1. It consists
of a cylindrical tool made from tungsten carbide grade K10 with diameter 12 mm and corner radius
1 mm and 2 mm that attached to the tool. In tool shank, it has a spring with a value of stiffness 157
N/m and the spring preload can be controlled. The tool moves and rotates on the workpiece surface
with once linear path. The overall setup and burnishing process parameter as shown in figure 2 and
table 1.

![Figure 1](image1.png)

**Figure 1.** The workpiece mounted on the dynamometer.

![Figure 2](image2.png)

**Figure 2.** Burnishing tool assembly.
Embedded thermocouple and FLIR thermal imager camera were used to measure the maximum workpiece temperature and maximum tool surface temperature, respectively. K-Type thermocouple wire (Nickel-Chromium) was embedded into the hole at 36.75 mm (Location 1) and 85.75 mm (Location 2) starting from the edge of the workpiece. The distance of endpoint thermocouple and the top surface of the workpiece approximately at 0.03 mm as shown in figure 3. The thermocouple is fixed into the place with the help of epoxy and silver substance which is to further increase the sensitivity and accuracy of the thermocouple. The eight-channel amplifier triggered and recorded the electric signal from the thermocouple wire and subsequently transferred into the DEWESOF software for acquiring the data. The thermal imager camera was used to record the temperature surrounding of the tool tip along the burnishing process.

Surface roughness tester (Mitutoyo SJ-400) was used to measure the surface roughness of the workpiece after undergo burnishing process. The standard reference used for this measurement is JIS1994 and the arithmetical average roughness, \( Ra \) value was measured at three sections on the burnished surface as shown in figure 4. Based on DIN EN ISO 4288, the cut-off length, \( \lambda_c \) was set at 0.8 mm and the evaluation length, \( ln \) is 4 mm. MQL and SCCO\(_2\) + MQL as the cooling techniques were applied in this experiment. The condition and the position of the nozzle for these cooling techniques as shown in table 2 and figure 5, respectively.
Figure 5. Position of nozzle.

Table 1. Burnishing process parameters.

| Parameters                          | Value(s)            |
|-------------------------------------|---------------------|
| Spindle speed, $N$ (rpm)            | 10,000              |
| Indentation force, $F$ (N)          | 750                 |
| No. of tool passes                  | 1                   |
| Feed rate, $f_r$ (mm/min)           | 200                 |
| Burnishing tool material            | Carbide (Grade K10) |
| Burnishing tool diameter, $d$ (mm)  | 12                  |
| Corner radius of tool, $R$ (mm)     | 1 (R1) & 2 (R2)     |
| Cooling Techniques                  | Dry, MQL, SCCO$_2$ + MQL |
| Work piece material                 | Carbon steel (SS400) |

Table 2. MQL and SCCO$_2$+MQL parameters.

| Cooling technique | Parameter                      | Levels          |
|-------------------|--------------------------------|-----------------|
| MQL               | Input pressure, $P$ (MPa)      | 0.4             |
|                   | Nozzle distance, $N_d$ (mm)    | 8               |
|                   | Lubricant type                 | Synthetic Ester |
|                   | Lubricant flow rate, $Q$ (l/hr)| 0.16            |
| SCCO$_2$ + MQL    | Input chamber pressure, $P_c$ (MPa) | 10.4          |
|                   | Nozzle distance, $N_d$ (mm)    | 8               |
|                   | Lubricant type                 | Synthetic Ester |
|                   | Lubricant flow rate, $Q$ (l/hr)| 2.61            |
3. Result and discussion

3.1. Burnishing thrust force

Figure 6 shows the results of thrust force under various coolant techniques and different corner radius of burnishing tool diameter 12 mm. The result shows SCCO$_2$ + MQL with high pressure input chamber has the lowest thrust force compared to the other conditions. The thrust force value at R2 under SCCO$_2$ + MQL condition was 3.5% and 11.2% lower than MQL and dry condition. The mixture of cryogenic gas and lubricant, which provides lubricating and cooling can reduce the burnishing force. The higher lubricant flow rate contributed to the higher quantity of lubricant being supplied towards the burnishing region. The application of lubricant reduced the friction coefficient between the tool and the workpiece [7]. As the lubricant was continuously supplied and pass through towards the burnishing region, the friction was reduced, thus resulted in enhanced tool ability to withstand the extreme force and pressure during burnishing process [8]. However, the lubricant diminished faster due to the amount of heat and extreme friction developed.

The graph also recorded at R1, dry condition has the highest average thrust force than MQL and SCCO$_2$ + MQL with 3% and 6.5% value of thrust force, respectively. The energy consumption in the burnishing operation was related with friction and burnishing force. Hence, lower burnishing force is more important to obtain to enhance burnishing quality and reduce the production cost. Obviously, this led to a higher value of friction during burnishing, thus increasing the cutting force. Lastly, the different corner radius of burnishing tool diameter 12 mm showed the R1 is has lower thrust force than R2 in each of cooling technique condition. It was recorded that the value of thrust force shows 1.88% reduction in SCCO$_2$ + MQL while 7.26% in dry condition and 2% relatively in MQL condition. This is due to the increase in pressure loading subjected by the smaller contact area of burnishing tool which is represented by R2. Hence, it enhanced the average thrust force of burnishing process.

![Figure 6. Result of burnishing force.](Image)

3.2. Burnishing temperature

The result of maximum workpiece and maximum tool surface temperature under various coolant techniques is presented in figure 7. It was observed in figure 7 (a) that dry condition contributes to the highest workpiece temperature compared to other cooling techniques. It shows that the temperature is increased up to 13% for corner radius of 2 mm, R2 at location 2 which is 85.75 mm starting from the edge, against MQL. This is attributed to the high friction between workpiece and burnishing tool.
force also demonstrates significant impact to an increase of both temperature. The higher average thrust force tends to increase the burnishing workpiece temperature. At this condition, force of kinetic friction increases due to the increase of thrust force, hence the generation of temperature is increased.

![Figure 7. Result of burnishing temperature.](image)

The lowest maximum tool surface temperature is recorded by SCCO$_2$ + MQL as shown in figure 7 (b). For example, under the burnishing tool of R1 at location 1 which is 36.75 mm starting from the edge, it reduces the tool surface temperature by 16% and 42.6% compared to the MQL and dry conditions. The mixture between carbon dioxide gas and lubricant tend to reduce the burnishing temperature and friction by removing the heat and lubricate the tool-workpiece interfaces. SCCO$_2$ + MQL penetrates to the burnishing zone easily due to the tiny particles with high velocity. These tiny particles can affected the effectiveness of cooling rate due to the tiny particles are more easily penetrate to the tool interface and reduce the temperature compare to the bigger particle such as on flood coolant condition [7].

![Figure 8. Result of surface roughness.](image)

3.3. Surface roughness
The graph of surface roughness of workpiece after burnishing process under different cooling techniques shown in figure 8. It was observed that SCCO$_2$ +MQL condition recorded the lowest surface roughness compared to the other cooling techniques. At SCCO$_2$ +MQL condition, the burnishing tool of 12 mm diameter with corner radius R2 exhibits 41.6% and 31.2% of reduction relative to the dry condition and MQL condition, respectively. Meanwhile, dry condition recorded the highest surface roughness, 15.2%
higher than MQL condition. Moreover, the burnishing tool of 12 mm diameter with different corner radius R1 and R2 shows the effect on the value of surface roughness. The burnishing tool R1 has the lowest surface roughness with decrement 34.66% compared to burnishing tool R2 in SCCO$_2$+MQL condition.

Based on the observation, it shows that the trend of surface roughness results is related to the trend of thrust force. Both thrust force and surface roughness produces higher value. As the thrust force is increased, the penetration of burnishing tool on the workpiece becomes deeper. At this condition, the amount of asperities of workpiece being deformed become higher and it increased the surface roughness of workpiece [3]. The corner radius of burnishing tool is another factor that contributes to the value of surface roughness. The larger corner radius of burnishing tool produces highest value of surface roughness. This can be relate to the larger corner radius of burnishing tool produces smaller contact area on the workpiece, thus produces deeper depth of indentation. Therefore, stirred volume on the workpiece surface becomes larger when large corner radius of burnishing tool is applied [10]. This study can be proved that the application of lubricant under MQL and SCCO$_2$+MQL conditions has improved the machinability of materials and reduce the force. Hence, the better surface roughness can be obtained.

4. Conclusions
This study investigated the effect of various cooling technique such as dry, MQL and SCCO$_2$+MQL and tool corner radius, and their respective impact on thrust force, temperature and surface roughness. SCCO$_2$+MQL was proven to be the most effective technique in burnishing of SS400 workpiece than other alternative techniques. This excellence cooling and lubrication of the process ensures a lower thrust force, temperature and surface roughness.

5. References

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