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The impact of process parameters on surface roughness and bushing in friction drilling

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Abstract
Friction drilling is considered a non-traditional hole making method in which the workpiece is penetrated by a conical rotating instrument and a bush is formed without producing chips in a single cycle. In the present work, using a CNC milling machine, the friction drilling process was carried out on Be-Cu C17200 plate material. The process parameters such as spindle speed and feed rate were performed over three levels of workpiece material thickness. Surface roughness, bush length, and the thrust force of the drilled holes were analysed following drilling. For optimal surface roughness and bush formation, it is noted that spindle speed and feed rate play a significant role in friction drilling. Higher feed rate and thrust force have a direct effect on greater roughness of the surface and increased bush length. Better bushing and surface roughness are given by an increase in spindle speed.

1. Introduction

Thin-walled materials are usually joined with welded or bolted joints in industries. Basically, due to the relatively small section thickness, excessive melting occurs during welding at the link point. A new non-traditional drilling method called ‘Friction Drilling (FD)’ was created by researchers to solve these problems. Recently, due to its chipless method of making holes without smoke, the friction drilling process has become popular. This method is also referred to as a thermal drilling process in which the instrument uses the heat produced by friction between a rotating conical instrument and the workpiece and creates a bush-like hole [1]. The length of the bush shaped is three times the thickness of the workpiece that provides better threading and clamp load available [2]. The different phases of the friction drilling process are shown in figure 1.

Miller [3] conducted thrust force investigations related to the drilling of cast metals through friction. The authors examined the effect of workpiece pre-warming, shaft speed, and feed rate on the thrust force and torque produced during the process of friction drilling. The results of this study showed that thrust force and torque had a crucial effect on both pre-warming and shaft speed. Feed speeds, on the contrary, had an inconsequential effect on these two aspects. In another study [4], the authors suggested a diagnostic technique using measured temperature to quantify thrust force and torque. Using a tungsten carbide drill instrument, the authors investigated the friction drilling mechanism on the AISI1020 grade steel. It is concluded that the experimental findings are well in line with numerical correlations. Further studies have also been performed [5] on the effects of tool wear on differences in thrust force and torque. The authors concluded that reducing the thrust force and torque could increase the number of drilled gaps.

The effects of axle speed and feed rate on temperature during the friction drilling process on the stainless steel pipe have been investigated [6–8]. The effect of workpiece materials on temperature and thrust force was investigated by aluminium, brass, and stainless steel [9, 10]. These authors found both a high generation of heat and a higher thrust force when stainless steel material was penetrated by the instrument. The consequences of friction angle, shaft speed, and feed rate on heat generation, thrust power, and torque have been checked [8, 11]. A parametric study [6, 12–15] was later presented to investigate the impact of process parameters on power and torque during the process of friction drilling for optimizing machining parameters.
In this present study using a CNC milling machine, friction drilling was carried out on Be-Cu C17200 plate material. Process parameters such as spindle speed and feed rate over three levels of thickness of the workpiece material were performed in the friction drilling phase. The effect of these process parameters on surface roughness, bush length, and thrust force of the drilled holes was examined after drilling.

2. Experimental setup

One of the most significant aspects of the process of Friction Drilling (FD) is that a sophisticated machine tool is not necessary. With the addition of a friction drilling tool to the machine spindle, the existing machine tools (drilling or milling) may be used for the friction drilling operation. In the present work, in a precision CNC vertical milling machine (Surya VF-30-CNC-VS), an experimental setup was developed to perform the friction drilling operation. To keep the Friction drilling instrument, a regular collet tool holder was used and the workpiece was held over the fixture to avoid slipping during the process. The tool used is made of tungsten carbide material and the diameter of the tool is 10.6mm. The photographic view of the experimental setup is shown in figure 2. For the experiments, process parameters such as spindle velocity 2500, 3000, 3500rpm, feed rate 40, 50, 60 mm min\(^{-1}\) were used. In this analysis, the workpiece material a hot forged beryllium copper (Be-Cu) C17200 was used in the FD process with dimensions of 120 × 80 mm with thicknesses of 2 mm, 2.5 mm, and 3 mm. Beryllium copper (Be-Cu) is a non-ferrous alloy. Due to its great mechanical properties and
corrosion resistance, Be-Cu is used for many applications in automobiles and aerospace industries. The material property of the beryllium copper (Be-Cu) C17200 is shown as a graph and micrograph of the material under a microscope shown in figure 3. Table 1 demonstrates the mechanical properties of the workpiece material.

3. Experimental results

3.1. Investigation of surface roughness (Ra) over process parameters
The involvement of process parameters that affect the roughness of the surface was plotted as a graph in figure 4. It is observed from the graph that surface roughness decreases as spindle speed and feed rate increase. The lowest surface roughness value observed 0.39 μm, 0.19 μm, 0.38 μm, and the highest surface roughness value is
2.67 μm, 0.57 μm, 1.75 μm for the workpiece’s 2 mm, 2.5 mm and 3 mm thickness. In table 2, the surface roughness values are tabulated.

3.2. Investigation of bush length (BL) over process parameters
The influence of process parameters on bush formation has been addressed in this chapter. The length of the bush is determined by utilizing a dino-lite digital microscope. The study reveals that when the speed is at level C, the length of the bush is at its highest height. In figure 5, a correlation is plotted between the process parameter and the bush length. There is an increase in frictional heat as the speed increases, which helps the material to soften and penetrate more. Concerning the above state, when there is an increase in feed rate, the condition changes. The length of the bush is poor when the feed rate is at level C. Due to the rise in feed rate, uniform frictional heat distribution is lower. Thus, low frictional heat contributes to a reduction in the length of the bush. The material’s analytical thickness also influences the length of the bushing. In table 3, the measured duration is tabulated. At the top, the shaped bushes will have a rigid shape. If the thread is carried out in a drilled cavity, these formations would be saturated. A sample representation of the bush being formed is shown in figure 6.

3.3. Investigation of thrust force (TF) over process parameters
The variance of the max thrust force obtained at different process parameters during the friction drilling process is shown in figure 7. It demonstrates that an increase in feed rate contributes to an increase in thrust force. The vibration between the tool and the workpiece is increased when the feed rate is increased, resulting in a higher thrust force. It is seen from the observation that the thickness of the workpiece also has a direct influence on the force of thrust. It takes much more force to penetrate as the workpiece’s thickness increases. Compared to the 3 mm thickness of the workpiece, the thrust force values for the 2 mm thickness of the workpiece are lower. A rapid heat increase due to friction at higher spindle speed softens the workpiece and smoothly penetrates, resulting in lower thrust force. Therefore, an increase in the speed of the spindle leads to a reduction in the thrust force. The measurement of the thrust force observed is plotted in figure 8.
4. Conclusion

On beryllium copper (Be-Cu C17200), friction drilling was done. The following findings were taken based on the observations.

1. The volume of material moving in the direction of the instrument impacts the thickness of the bushing wall at the top of the hole and the height of the bushing height at the bottom of the hole with the influence of the spindle speed. The process temperature is directly related to the speed of the tool rotation and the use of higher tool speeds has been calculated to result in maximum temperature increases relative to the feed rate.

2. There was a significant improvement in the observed surface roughness with a rise in feed rate. The value of surface roughness was greater at a high feed rate and lower at a low feed rate. The surface roughness was
found to be high at a 70 mm min\(^{-1}\) feed rate. The proposed Spindle speed in the experiment had less impact on surface roughness.

3. At optimum criteria, the length of the bush of the drilled hole was three times the thickness of the workpiece. The rise in spindle speed and the decrease in feed rate gave the internal screw a better bush length, providing better threading. As seen from the experimental studies, a major influence on the resulting bushing wall thickness and bushing height has been determined by the growing instrument diameter and material thickness. Depending on the material thickness, the bushing height increases periodically. The highest bushing height and the lowest bushing height were obtained as 6.89 mm and 4.1 mm while the material thickness were 3 mm and 2.5 mm.

**Data availability statement**

The data that support the findings of this study are available upon reasonable request from the authors.
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