MACHINING OF D2 HEAT TREATED STEEL USING ABRASIVE WATER JET: THE EFFECT OF STANDOFF DISTANCE AND FEED RATE ON KERF WIDTH AND SURFACE ROUGHNESS

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Abstract

This paper discusses the machining of D2 heat treated steel using Abrasive Water Jet (AWJ). D2 steel is an alloy of high-carbon, high-chromium, air-hardened steel, which has high wear resistance and toughness, and is generally used in tool and die making. The experimental investigation has been carried out to find the effect of process parameters such as standoff distance and the feed rate on the kerf width and on the surface roughness (Ra) value of the kerf generated by AWJ. It has been observed that, in single pass machining, for the same increase in standoff distance, the top kerf width increases (≈18%) whereas the bottom kerf width decreases (≈25%). The results also show that, the increase in standoff distance and feed rate increases the surface roughness (Ra) value. However, in multi-pass (two) machining, it has been observed that, at the same feed rate the difference between top and bottom kerf widths is considerably less (≈27%) which results in the reduction of kerf taper, also similar reduction is observed in surface roughness (Ra) value

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1. INTRODUCTION

Manufacturing industry is becoming more time conscious and quality oriented with the emerging global economy. Need for the development of rapid manufacturing technology is increasing in modern industries. These trends have forced the industries to use non-conventional machining processes such as Electric Discharge Machining, Chemical Machining, Laser Machining, Abrasive water jet (AWJ) machining, etc. for material processing during production. The capability of machining intricate shapes with good dimensional accuracy in hard, brittle and composite materials has made the AWJ machining process as an inevitable and one of the most popular non-conventional machining tools (2).

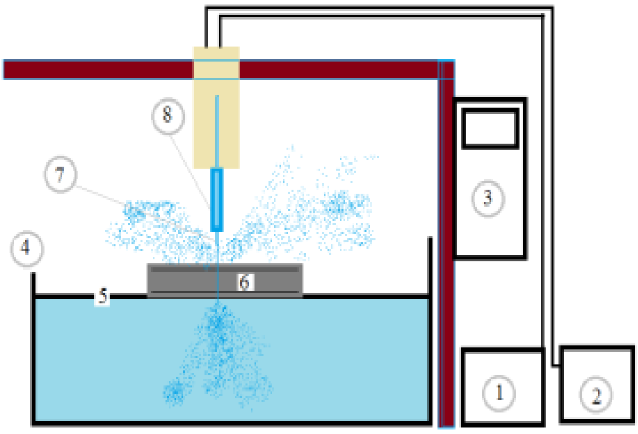
D2 steel is an air hardened, high-carbon, high-chromium tool steel, generally used in tool and die making applications. It has high wear and abrasion resistant properties. Because of the high carbon content D2 steel when heat-treated develops hardness up to a range of 60 - 65 HRC. Addition of chromium as an alloying element enhances the corrosion resistance properties in the hardened condition when compared to the conventional materials.

The influence of process (input) parameters such as operating and abrasive parameters on the performance of AWJ machining was investigated by many pioneering researchers. It is observed from the work of Hashish (3), Kovacevic et. al. (4), Kantha Babu et. al. (5) and Srinivasu et. al. (6) that, the operating pressure, feed rate and standoff distance are the significant process parameters which influence the AWJ machining performance parameters such as material removal rate, kerf geometry and surface roughness. Machining performance analysis of various types of abrasive particles used in AWJ machining reveals that silicon carbide abrasive particles exhibited better machining performance followed by aluminum oxide and garnet materials (7). Boud et. al. (8) studied the influence of abrasive morphology on AWJ machining of a titanium alloy and found that irregular shaped abrasives led to higher material removal and spherical shaped abrasive particles produced better surface finish. Chithirai et. al. (9) and Wang (10) investigated the effect of process parameters on the responses during AWJ machining of copper and alumina ceramics materials and developed response predictive models. Similar study was conducted by Farhad et. al. (11) on 6063-T6 Al alloy. Shanmugam et. al. (12) found that kerf compensation techniques can substantially reduce the surface taper produced on alumina ceramics. Though the investigations on the machining of various materials such as aluminum, brass, titanium, steel and tool steel were reported, but no attempt has been made to machining of D2 steel material using AWJ. Hence, the present work aims at investigating the effect of standoff distance and feed rate as well as multi-pass machining on kerf width and surface roughness.

2. EXPERIMENTAL WORK

2.1 Experimental Setup

Figure 1 shows the schematic diagram of AWJ machining test rig. The AWJ machine consists of an intensifier pump that generates high pressure water, abrasive feeding system and a cutting head which generates AWJ by abrasive injection. The movement of the cutting head on the work-piece is controlled by computer numerical control system. The eroded material during machining is collected at catcher tank in which the remaining energy of the spent jet gets dissipated.



1- High pressure pump with intensifier, 2- Garnet supply unit, 3- CNC control panel, 4- Catcher tank, 5- work support clamp, 6- Work piece, 7- AWJ, 8- Nozzle head for generating AWJ

Fig 1: AWJ machining test rig

2.2 Work Material

AISI D2 steel specimen (procured from FENFEE technologies, Bangalore) is a high-carbon, high-chromium cold work steel, which is generally used for manufacturing of tools and dies. The density of AISI D2 steel is 7.7×10^3 kg/mm^3 and the melting point is 2590°F. The average hardness of the test specimen is found to be 58HRC. The specimens are wrapped in a stainless steel sheet prior to air hardening process to provide some degree of surface protection from scaling. The temperature of the furnace is maintained at 1560°F and further the specimens are cooled in the furnace at 20°F. Later the specimens are tempered twice by heating up to 700°F to develop deep hardness.

2.3 Experimental Plan

The experimental investigation has been carried out to find the effect of process parameters such as standoff distance (SOD) and feed rate on the kerf width and the surface roughness (Ra) of the kerf generated by AWJ. The process parameters (input factors) and their settings are listed in table 2. The experiments are conducted on a test specimen of 8 mm thick by varying SOD and feed rate (varying one factor at-a-time), the operating pressure and abrasive flow rate being kept constant. Machining has been done by traversing the AWJ at single pass and double passes on the test specimens. Response parameters namely kerf width and surface roughness are measured using tool room microscope and Taylor and Hobson Surtronic instrument respectively

Table 1: Process parameters

Process parameters	Settings
Pressure	240 MPa
Standoff distance	1 - 1.5 mm
Abrasive flow rate	330 gm/min
Feed rate	90 - 175 mm/min
Abrasive used	Garnet (80 mesh)
Nozzle diameter	0.76 mm (Make: Kennametal)

3. RESULTS AND DISCUSSION

3.1 Effect of Standoff Distance on Kerf Width and Surface Roughness (R_a)

Single pass machining has been carried out by varying the SOD and all the other process parameters such as the feed rate, operating pressure and abrasive flow rate are kept constant at the suitable values. The experimental responses plotted in figures 2(a) and 2(b) indicate the effect of variation of SOD on kerf width and surface roughness (Ra) values respectively. It is seen from figure 2(a) that, the increase in SOD results in the increase of top kerf width and decrease in bottom kerf width. As the SOD increases, the jet diameter increases due to radial expansion and jet impinges on the workpiece at wider region, hence increase in the top kerf width. However, the decrease in bottom kerf width with increase in SOD is due to the fact that, as the jet penetrates into workpiece, it loses energy, as a result, the quantity of spent abrasives flowing backwards (which cause the erosion of kerf walls) progressively diminishes, hence decreasing trend.

Figure 2(b) shows that, the surface roughness increases with increase in SOD. As explained earlier, the increase in SOD results in loss of jet energy due to jet expansion and penetration into the workpiece. The low energy abrasive particles that participate in secondary cutting, instead of smoothing the kerf walls (cut surface), produce scratches as the abrasive particles do not have sufficient energy to erode the material.

The photographs of the kerf widths (top and bottom) and surface roughness of the machined test specimens are shown in figures 3(a), 3(b) and 3(c) respectively. In case of single pass machining, it can be observed from the figure 2(a), for the same increase in the SOD, the top kerf width shows an increasing trend (average of ≈18%) whereas the bottom kerf width shows decreasing trend (average of ≈25%) other parameters being kept constant. It is seen from figure 3(c) that, as the SOD increases, there are more striations which indicate the increase in surface roughness.

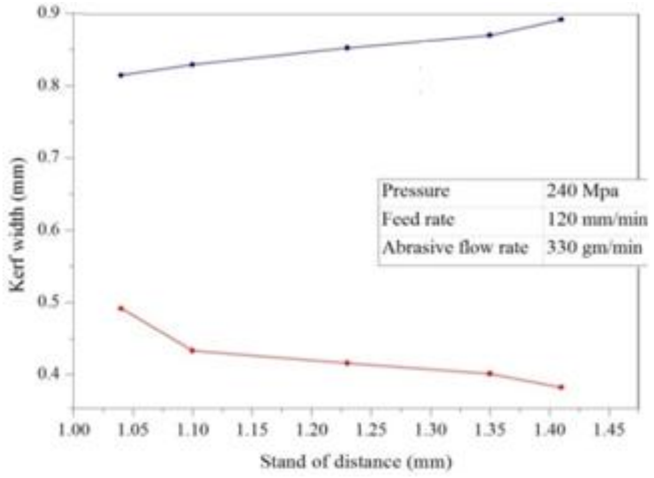


Fig 2(a): Effect of variation of SOD on Kerf width

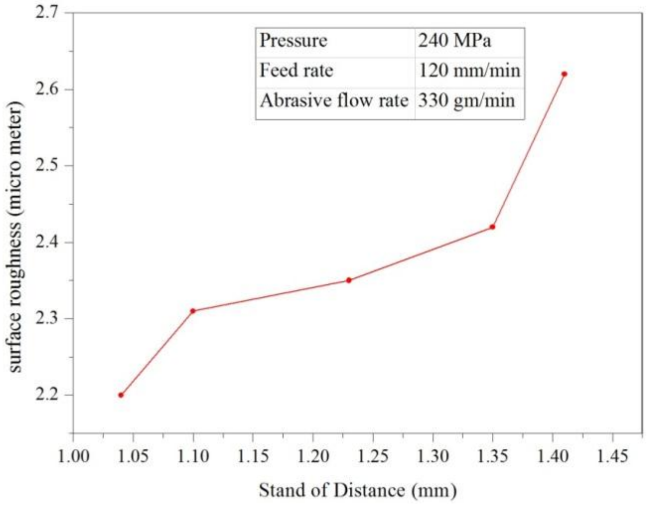


Fig 2(b): Effect of variation of SOD on Surface roughness (R_a)

Fig 3(a): Machined specimen - Top kerf width on varying SOD

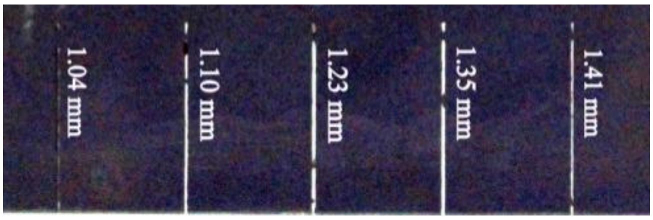
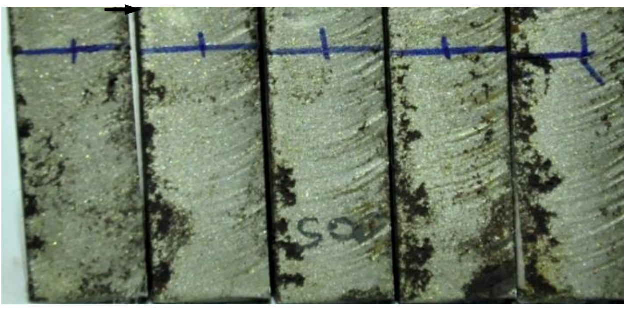


Fig 3(b): Machined specimen -Bottom kerf width on varying SOD



SOD 1.04mm

Fig 3(c): Machined specimen – Surface roughness (Ra) on varying SOD

3.2 Effect of Feed Rate on Kerf Width and Surface Roughness (R_a)

Single as well as multi-pass (two) machining has been done by varying the feed rate and keeping the other process parameters constant at the suitable values. The effect of single and multi-pass machining on both (top and bottom) kerf widths at various feed rates is shown in figure 4. It may be observed that for the same value of the feed rate, the kerf widths (top and bottom) produced in multi-pass machining is higher than that obtained in single pass machining in each case of feed rate. During the second pass machining, the abrasive particles that flow backwards have more energy (lose less energy as they travel less compared to single pass) resulting more material erosion and hence more kerf widths. Further, both the kerf widths decrease with increase in feed rate which is generally observed, because the jet exposure time on the workpiece reduces with increase in feed rate.

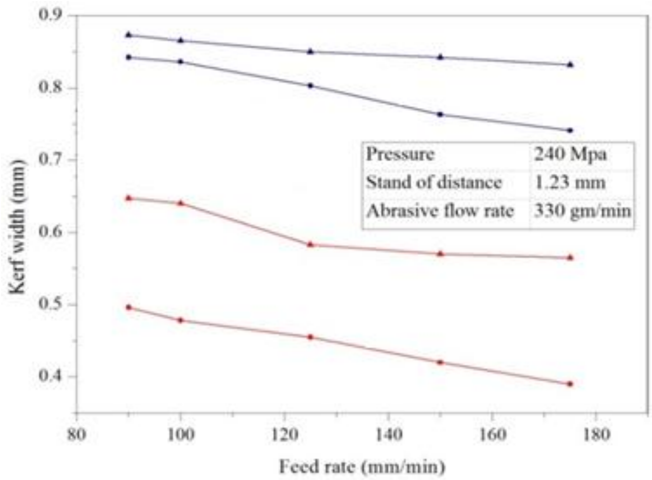


Fig 4: Single and multi-pass machining - Kerf width on varying feed rate

Figure 5 shows that, the increase in feed rate results in increasing surface roughness. At lower feed rate, sufficient time is available for the jet to perform primary cutting as well as secondary cutting (smoothing) resulting in the lower surface roughness value (R_a). But at higher feed rate, the time available is relatively insufficient for the abrasives to perform secondary cutting resulting striations, hence higher surface roughness value.

Further it may be observed from figures 6(a) and 6(b) that at the same value of the feed rate, the surface roughness produced in multi-pass machining is smaller than that obtained in single pass machining. During the second pass machining, as the depth of penetration is less, the abrasive particles have more energy (lose less energy as they travel less compared to single pass) to perform complete secondary cutting resulting less number of striations, hence less surface roughness. However, in multi-pass machining, it has been observed that, at the same feed rate the difference between top and bottom kerf widths is considerably less (≈27%) compared to that of single pass machining which leads to reduction in the kerf taper, also similar reduction is observed in the surface roughness (R_a) value.

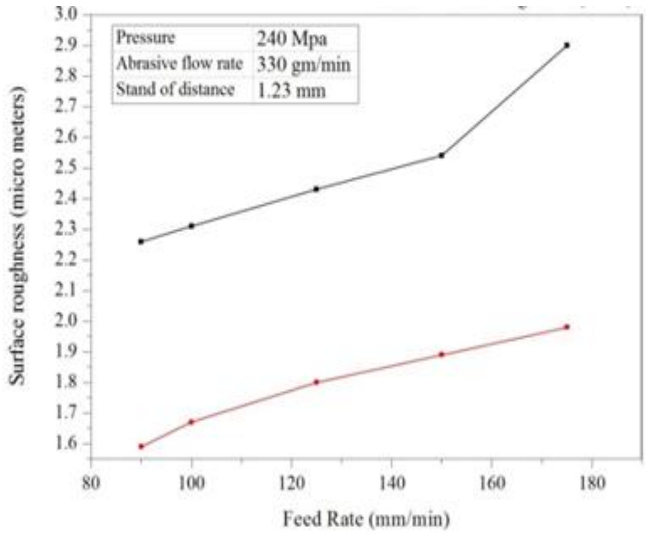
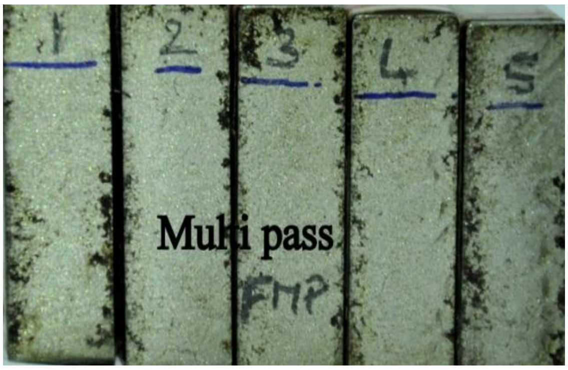


Fig 5: Single and multi-pass machining – Surface roughness on varying feed rate



Feed rate: 1 – 90 2 – 100 3 – 125 4 – 150 5 – 175

Fig 6(a): Multi pass machining – Surface roughness on varying feed rate

Feed rate: 1 – 90 2 – 100 3 – 125 4 – 150 5 – 175

Fig. 6(b): Single pass machining – Surface roughness on varying feed rate

4. CONCLUSIONS

Based on the experimental results reported in the previous section, the following major conclusions have been drawn with regard to AWJ machining of D2 heat treated steel.

- In single pass machining, for the same increase in the SOD, the top kerf width shows an increasing trend (average value of ≈18%) whereas the bottom kerf width shows decreasing trend (average of ≈25%) other parameters being kept constant.
- The surface roughness increases with increase in standoff distance and feed rate.
- However, in multi-pass (two) machining, it has been observed that, at the same feed rate the difference between top and bottom kerf widths is considerably less (≈27%) compared to that of single pass machining which leads to reduction in the kerf taper, also similar reduction is observed in the surface roughness (R_a) value. Hence, multi-pass machining is recommended for cutting thick components.

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