Effect of Machining Parameters on Surface integrity during Dry Turning of AISI 410 martensitic stainless steel

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Abstract: The primary method of material removal from a cylindrical workpiece is conceivable by using turning process.This paper presents a comprehensive analysis of surface integrity in dry machining of AISI 410 martensitic stainless steel which is widely used material for automotive and aerospace applications. In the present work, the effects of turning process parameters such as cutting velocity, feed and depth of cut in dry turning of martensiticstainless steel has been investigated. Taguchi orthogonal array has been implemented to investigate the effect of process parameters on surface roughness and tool-workpiece interface temperature. A detailed study about the chip morphology and machined surface has been carried out using scanning electron microscope. It was noticed that golden color thick long ribbon type chip was produced at dry condition and side flow has been observed in chip.
Key words: Dry Turning, Surface roughness, martensitic stainless steel, SEM.

1. Introduction

In practice, Martensitic stainless steel finds greater importance in many industrial applications like automotive and aerospace industry due to its special noticeable mechanical properties which helps in smooth functioning of the component. By nature itself it has complex microstructure good corrosion resistance property and even harder than austenitic stainless steel. It was found that surface integrity greatly affected by cutting tool geometry [1].Though different machining processes are used in numerous applications, basically Turing process finds itself one of primary machining process to produce desire shaped components to suit the point of applications. The overall performance and life span of machined component mainly rely on nature of surface attained during the machining process. It is well-known that surface integrity of a machined surface is influenced by numerous factors such as cutting speed, feed, and depth of cut and even it has a direct effect on functional performance of the component. M.Y. Noordin et al. [2] have studied the Dry turning of tempered martensitic stainless tool steel using coated cermet and coated carbide tools. Study revealed at low feed rate, snarled cock screw chips are produced regardless of the cutting speed and cutting speed at 0.16 mm/rev, long, cock screwchips are obtained. G. Krolczyket al. [3] investigated the microhardness analyses in dry and wet machining of duplex stainless steel. The microhardness of surface integrity for various cutting speeds were compared. It has been shown that wet cutting speed leads to the decreased surface integrity hardening depth. V. GarcíaNavas et al. [4] have discussed the surface integrity of AISI 4150 (50CrMo4) steel turned with different types of cooling-lubrication. Study proved that cryogenic machining is the best solution since it reduces machining problems of heating, leading to tool life

improvement and better surface integrity of turned components. Also GrzegorzKrolczyk et al. [5] reported that Surface integrity is an important in determining corrosion resistance, and also in fatigue crack initiation. The investigation included analysis of microhardness of surface integrity for different cutting parameters in dry turning process of 1.4541 austenitic stainless steel. It has been shown that increase of cutting speed leads to the increase of Surface integrity hardening depth.
In the present study, development of surface and subsurface changes during turning of Martensitic stainless steel have been studied in related to surface roughness, surface defects and a detailed study of the chip morphology and machined surface has been carried out using scanning electron microscope. It was noticed that golden color thick long ribbon type chip was produced at dry condition and side flow has been observed in chip. This detailed investigation gives depth insight on how machining parameter affects the functional performance of the component and helps to optimize the machining parameters to achieve an optimum performance during machining.

2. Experimental Work

A Commercially available AISI 410 martensitic stainless steel was used as work material. The obtained material with a dimension of 150 mm length and 20 mm diameter has been taken for machining. The chemical composition of the AISI 410 martensitic stainless steel sample is shown in Table 1. Conventional Turning experiments were performed in dry condition by using L9 orthogonal array. The rangeof machining factors and their levels to be controlled during machining were taken for the experiments given in Table 2 and L9 orthogonal array and response presents in Table 3. For the turning experiments, three different spindle speed, feed rate and depth of cut were considered. The experimental setup as shown in Fig 1.

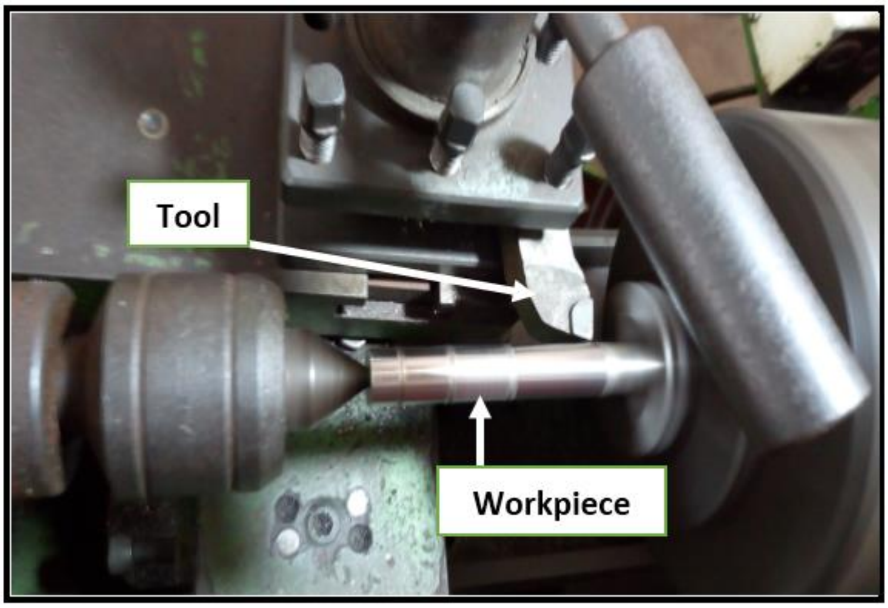

Fig 1: Conventional Turning of AISI 410 MSS

Table 1: Chemical composition of AISI 410 martensitic stainless steel

Constituents	C	Mn	Si	Cr	Ni	S	P
Wt. (%)	0.15	1.0	1.0	11.5-13.50	0.5	0.03	0.04

3. Design of Experiments

Turning experiments were performed based on Taguchi's design of experiment. Experimental trials were performed based on Taguchi's L9 orthogonal array which consists of all possible combinations of input process parameters along with their levels. Values of spindle speed, feed rate and depth of cut were varied to study their effects on surface roughness and Taguchi's L9 experimental trials helped in reducing number of experiments while making the process economical. Turning process parameters and their levels are tabulated in Table 2 and implemented Taguchi's L9 orthogonal experimental trials and corresponding surface roughness are indicated in Table 3.[6,7]

Table 2: Input parameters and their levels

Input parameters	Symbol	Levels		
		L1	L2	L3
Spindle speed (rpm)	A	315	500	775
Feed rate (mm/rev)	B	0.143	0.191	0.238
Depth of Cut (mm)	C	0.4	0.6	1.0

Table 3: L9 orthogonal array and output response

Sl No	**Spindle speed (rpm)**	**Feed rate (mm/rev)**	**Depth of Cut (mm)**	**Surface Roughness (µm)**
01	315	0.143	0.4	4.67
02	315	0.191	0.6	5.56
03	315	0.238	1.0	6.61
04	500	0.143	0.6	2.78
05	500	0.191	1.0	6.13
06	500	0.238	0.4	6.30
07	775	0.143	1.0	2.77
08	775	0.191	0.4	3.85
09	775	0.238	0.6	5.72

4. Measurement of surface roughness

The surface roughness of the machined component was measured by using Mitutoyo Surface roughness tester (SJ- 301) at three different locations and average value is taken as process response. The evaluation length of 2.4mm was used to measure the surface roughness with a stylus speed of 0.5mm/s.

5. Results and Discussion

5.1. Effect of input parameters on Surface roughness:

1. Mean effects plot for effect of spindle speed, feed rate and depth of cut on surface roughness are shown in Fig 2. From the mean effects plot it can be seen that surface roughness decreases with increasing spindle speed, increases with increasing feed rate and exhibits a drop-and-rise behavior with increasing depth of cut. This decrease in surface roughness with increasing spindle speed was due to thermal softening of the work piece material [11]. At higher spindle speed, more heat accumulates in the machining zone which leads to restructuring of the machined surface. This reduces flaws and defects by wiping out the excess material from the machined surface and hence surface roughness reduces with increasing spindle speed. It can also be observed that with increasing feed rate surface roughness increases. With increasing feed rate, friction between

workpiece and tool increases due to larger cross sectional area in deformation zone and hence leads to higher surface roughness. From Fig 2 it can be observed that with initial increase of depth of cut from 0.4 mm to 0.6 mm surface roughness reduces. Beyond 0.6 mm, i.e. at 1.0 mm depth of cut surface roughness increases. This can be attributed to thermal softening phenomenon occurring during transition from 0.4 to 0.6 mm, where more volume of material gets involved in the machining process and leads to a drop in surface roughness. However, when depth of cut increases, more amount of material in deforming volume leads severe plastic deformation and therefore machined surface exhibits higher surface roughness. The optimal setting parameters to obtain lower surface roughness are A3-B1-C2 (775rpm, 0.143mm/rev-0.6mm).

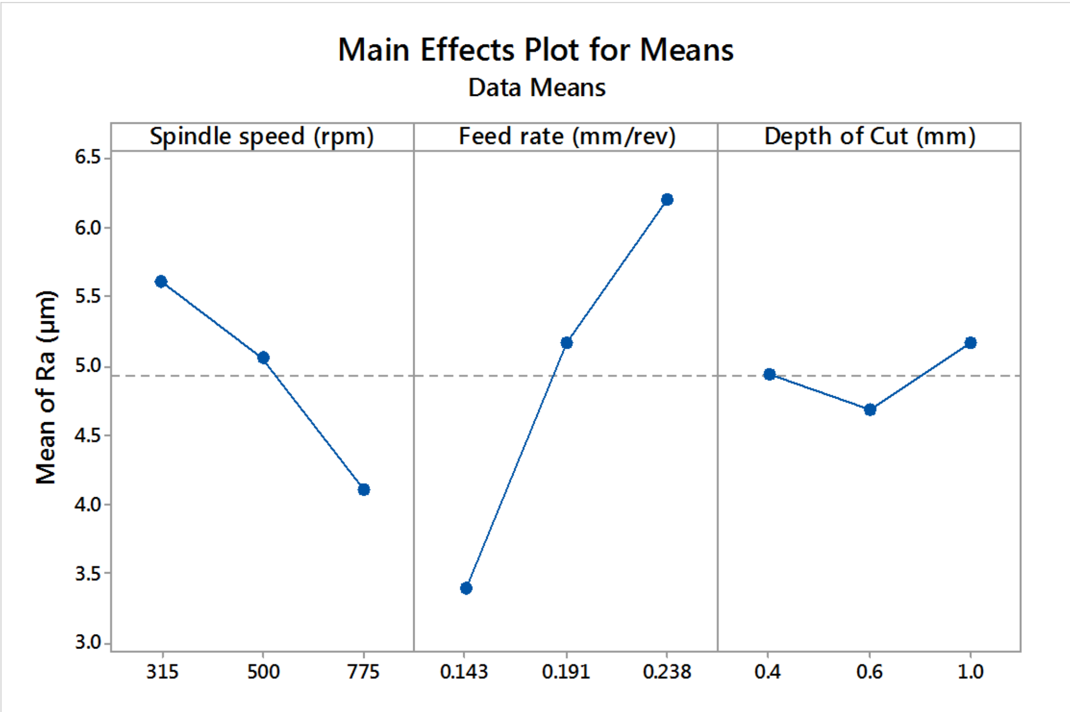

Fig 2: Effects plot for surface roughness

5.2Chip Morphology:

Figure 3 shows the chips produced by the cutting tools investigated at different cutting conditions. Chips are formed by the shearing action at the shear plane. During the shearing action, many aspects of the cutting process are affected by the process of plastic deformation in the cutting zone, such as: surface finish, dimensional accuracy, cutting forces, temperature and tool life [10]. The chip produced by the tool is light brown in color at lower cutting conditions, while it is darker at the higher conditions. The change in the color of the chips produced is an indication of the heat caused by the intense temperature at the cutting zone. Continuously cut chips, which entangle the tool holders, were produced at the lower cutting speed (see Fig. 3, 1-3). At the higher cutting speed, continuous chip with darker color was produced. The chips formed by lower speed and feed were slightly thinner compared to the ones formed at higher speeds and feed rate as investigated [9]. The appearance of localized deformation of the primary deformation zone started at low cutting speeds and became more visible at higher cutting speeds. Cracks in the secondary shear zone were not observed in the chip sample investigated but evidence of clearly defined thin white layer was observed as shown in Fig4. The degree of segmentation increased as the cutting speed increased as a result of softening of the

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workpiece material, which lead to more adiabatic shearing in the primary zone of the chip formed. Long and thin chips were formed with lower equivalent shear strain as opposed to turning soft steel.

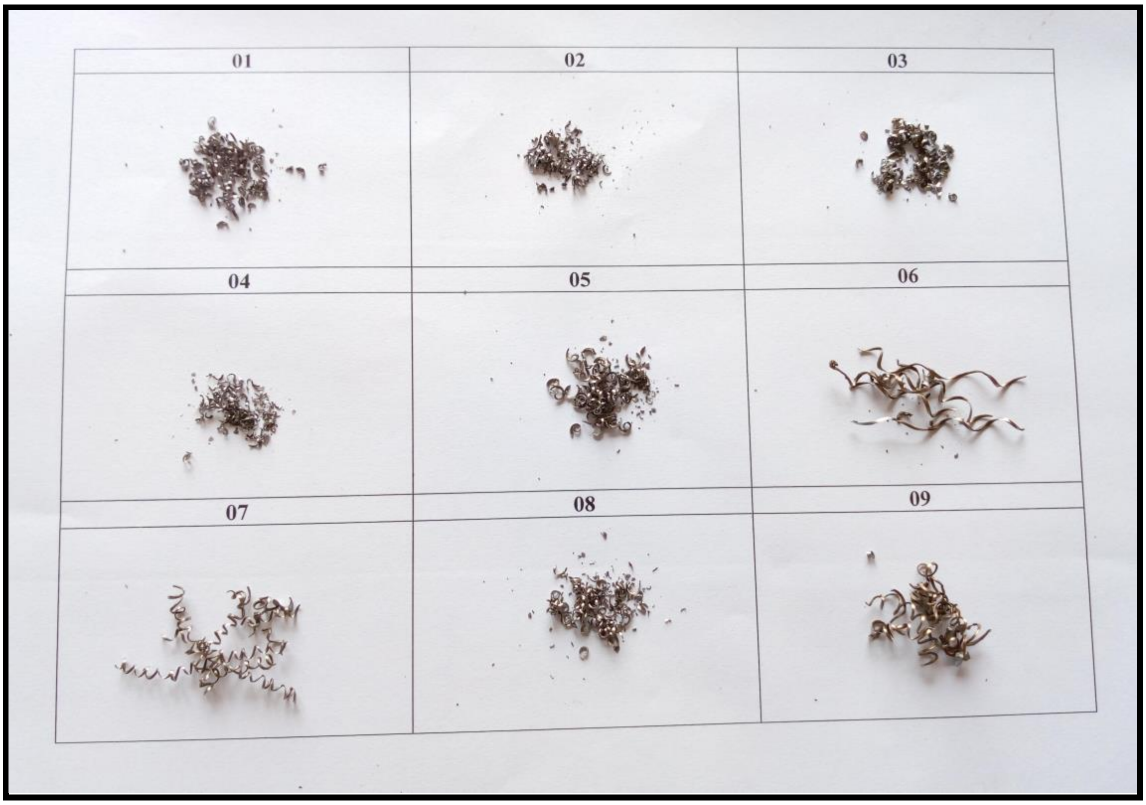

Fig 3: Forms of chip generated at varying machining conditions.

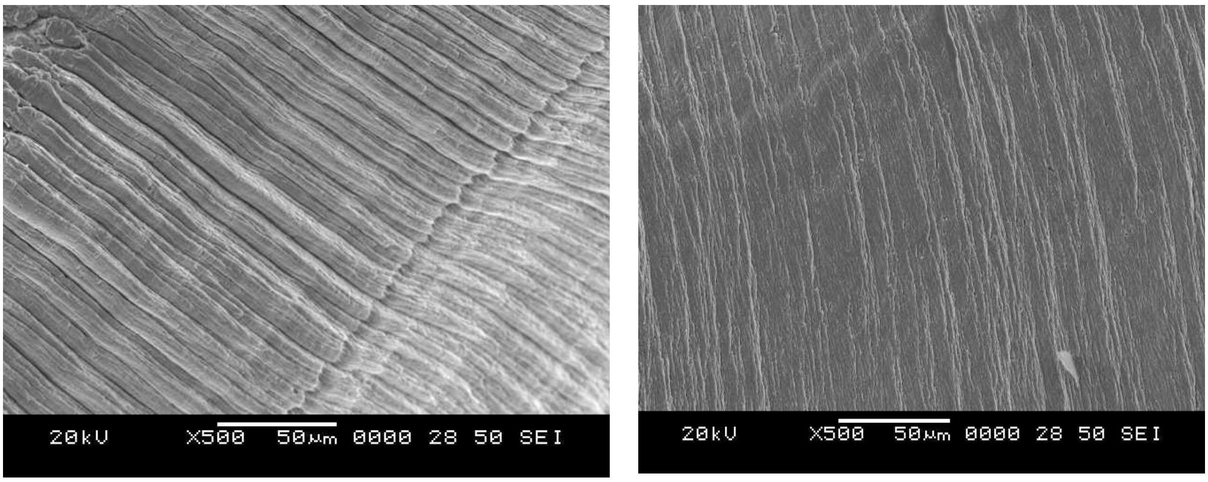

Fig 4: SEM images of the chip produced at(a) Spindle speed = 775 rpm, feed rate = 0.143 mm/rev, Depth of cut = 1 mm (b) Spindle speed = 775 rpm, feed rate = 0.238 mm/rev, Depth of cut = 0.6 mm

5.3 Machined Surface Morphology:

SEM images of the surface produced at different process parameters is as depicted in Fig 5. It is evident from the Figure 5 that surface defects like side flow, debris, grooves and adhered micro particles were observed to be present at dry condition. It is because of the variety of tool geometry formed at that particular machining condition. Feed marks have been observed at higher spindle speed, feed rate and depth of cut because of the high temperature formed at the tool and workpiece interface. In dry turning, as the temperature at the tool and the workpiece interface increases, it leads to thermal softening effect. Surface roughness of the workpiece increases because of the effect of thermal softening [8].

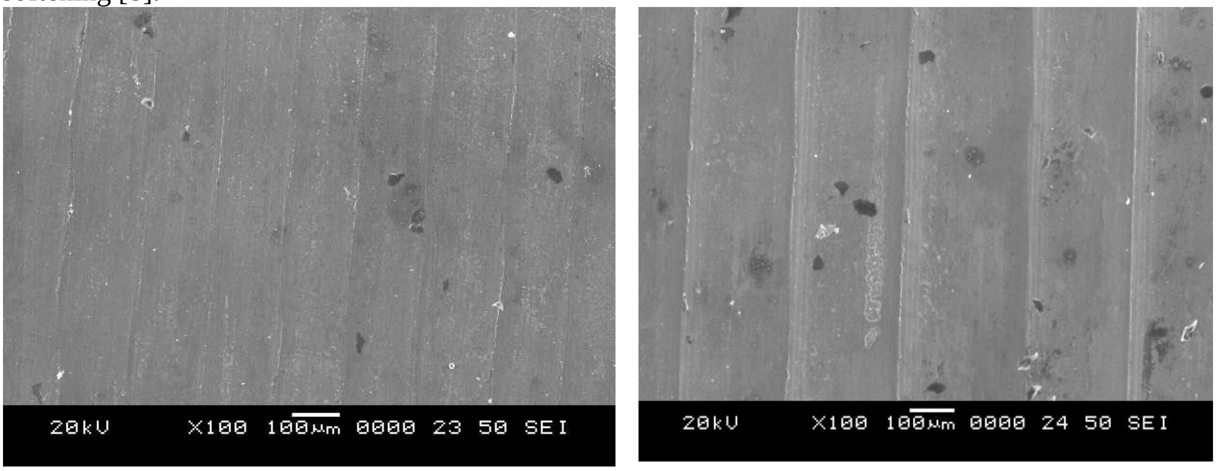

Fig 5: SEM images of the Machined surface at(a) Spindle speed = 775 rpm, feed rate = 0.143 mm/rev, Depth of cut = 1 mm (b) Spindle speed = 775 rpm, feed rate = 0.238 mm/rev, Depth of cut = 0.6 mm

6. Conclusion

Surface integrity characteristics of AISI 410 martensitic stainless steel by conventional dry turning have been investigated and reported. On the basis of obtained results the following conclusions can be drawn:

- The surface roughness decreases with increasing the spindle speed which plays a significant role during turning. The optimal setting parameters to achieve lower surface roughness forAISI 410 martensitic stainless steel are A3-B1-C2 (775rpm, 0.143mm/rev-0.6mm).
- At lower speed, continuous chips were formed and at higher speed darker color chips were obtained because of the high temperature produced at the tool-workpiece interface.
- Thinner chips were formed at lower speed and feed rate when compared to higher speed and feed rate.
- Feed marks have been generated at higher speed, feed and depth of cut.

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