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Machinability of Multiphase Microalloyed Steel

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Abstract

The machining of multiphase (ferrite-bainite-martensite) microalloyed steel was carried out in a high speed lathe to assess the machinability. The mechanical properties of multiphase (ferrite-bainite-martensite) microalloyed steel were analogous to those of quenched & tempered steels. The influence of machining parameters such as cutting speed, feed rate and depth of cut on cutting force and surface roughness was studied. The result shows that the feed rate and depth of cut influence more on cutting force and for surface roughness the only influencing parameter is feed rate. Optical and scanning electron microscope were used to find the microstructure and surface topography.

Keywords: Multiphase microstructure; machinability; cutting force; surface roughness.

1. Introduction

Microalloying elements are added to structural steels to refine the austenite grain size, to lower the transformation temperature and to impart precipitation hardening [1]. Vanadium microalloyed (MA) medium carbon steels are widely used in automotive industry due to their improved mechanical properties [2]. The multiphase (ferrite-bainite-martensite) microalloyed steel was produced through two step cooling (TSC) procedure after forging followed by annealing [3]. The mechanical properties were comparable to those of quenched and tempered steels. In the present study machining characteristics of the multiphase microalloyed steel are evaluated.

1.1. Experimental Procedure

The experiments were conducted in a high speed lathe to assess the cutting force. The chemical composition of the work material is C 0.38, Si 0.68, Mn 1.5, P 0.022, S 0.06, V 0.11, N 0.066, Cr 0.18, Fe balance. The hardness of the material is in the range of 400 to 430 HV. The yield strength of the material is 1384 MPa.

Uncoated tungsten carbide cutting tool of SNMG 120408 was used to machine the work material. Kistler dynamometer was used to measure the cutting force and Mahr perthometer was used to measure surface roughness. To reduce noise in the acquired signal a low pass filter was used. The process parameters considered were speed, feed and depth of cut and their levels are shown in Table 1. Taguchi L9 orthogonal array was employed for experimental design and smaller the better quality characteristics were chosen to find the signal to noise ratio [4]. Optical and Scanning electron microscope were employed to study the microstructure of work material and morphology of the chips. The experimental results obtained for various cutting parameters are shown in Table 2.

Table 1 Cutting Parameters

Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)
60	0.1	0.2
80	0.2	0.4
100	0.3	0.6

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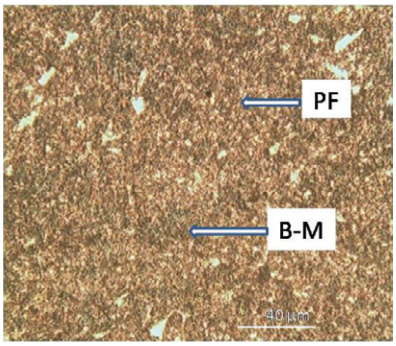
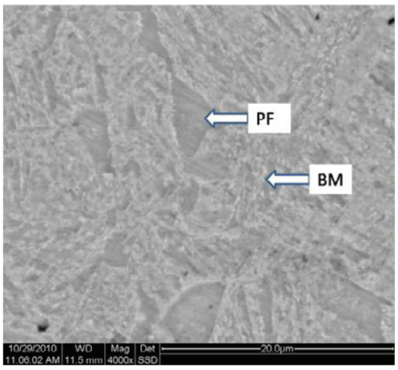
1.2. Microstructure of the multiphase steel

The micrograph obtained through optical and scanning electron microscope (SEM) of the work material is shown in Figure 1. The samples were etched with 2% Nital to see the microstructure of the steel. Polygonal ferrite (PF) and bainite-martensite (BM) colonies are seen in the microstructure.



(a)



(b)

Fig. 1. Micrograph of multiphase microalloyed steel (a) Optical (b) SEM

Table 2. Experimental results for Cutting Force and Surface Roughness

Cutting Condition	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Cutting Force (N)	Surface Roughness (μm)
1	60	0.1	0.2	127	1.20
2	60	0.2	0.4	210	1.70
3	60	0.3	0.6	627	3.10
4	80	0.1	0.4	213	0.80
5	80	0.2	0.6	415	1.20
6	80	0.3	0.2	298	3.50
7	100	0.1	0.6	259	0.61
8	100	0.2	0.2	212	1.44
9	100	0.3	0.4	456	3.10

2. Result and Discussion

2.1 Optimal cutting conditions

The optimal cutting conditions for getting minimum cutting force are shown in the Fig. 2 and the optimal parameters are found to be 60 m/min, 0.1 mm/rev, 0.2 mm. Similarly for minimum surface roughness the optimal parameter are 100 m/min, 0.1 mm/rev, 0.6 mm and is shown in Fig. 3.

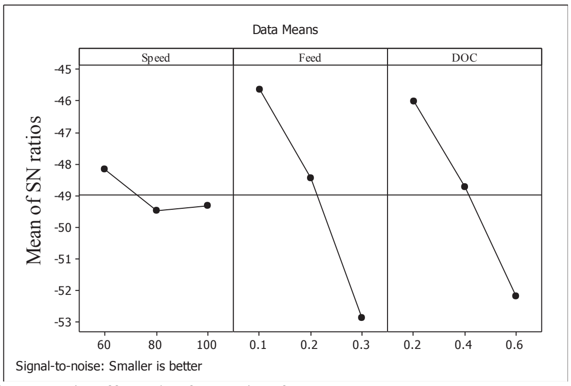


Fig. 2. Main effect plot for cutting force

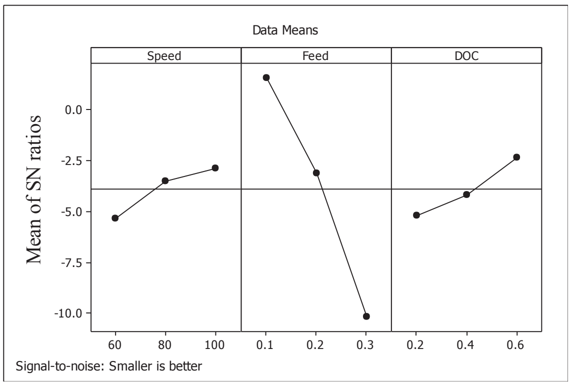


Fig. 3. Main effect plot for Surface Roughness

2.2 Effect of Cutting Parameters

Analysis of variance (ANOVA) for cutting force shows that the feed rate (55.29 %) influences more than depth of cut (39.66 %) and cutting speed (2.15%). Similar trend is observed while machining quenched and tempered steels [5, 6] and also the cutting force acquired is almost half of the cutting force recorded while machining high strength low alloy (HSLA) steel [5]. Similarly for surface roughness the only influencing factor is feed rate (90.16%) than other two parameters namely depth of cut (5.32%) and cutting speed (4.16%). The ANOVA results obtained for cutting force and surface roughness are shown in Table 3 and Table 4.

Table 3 ANOVA for cutting force

Symbol	Cutting Parameter	Degree of freedom	Sum of squares	Means square	Contribution (%)
A	Cutting Speed	2	3.11	1.55	2.15
B	Feed rate	2	79.78	39.89	55.29
C	Depth of cut	2	57.23	28.61	39.66
	Error	2	4.13	2.06	2.86
	Total	8	144.27		100

Table 4 ANOVA for Surface Roughness

Symbol	Cutting Parameter	Degree of freedom	Sum of squares	Means square	Contribution (%)
A	Cutting Speed	2	9.67	4.83	4.16
B	Feed rate	2	209.17	104.58	90.16
C	Depth of cut	2	12.36	6.18	5.32
	Error	2	0.77	0.38	0.331
	Total	8	231.98		100

3D surface plot explore the influence of feed rate and depth of cut for cutting force and surface roughness. From Fig. 4 the lowest force is recorded when feed rate and depth of cut are at minimum level. Whereas from Fig.5 minimum value for surface roughness is obtained at lower feed rate with maximum depth of cut.

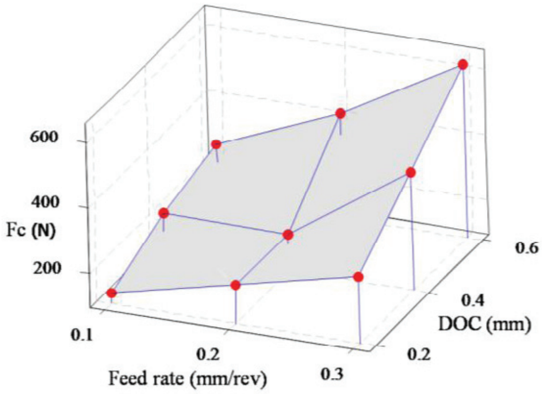


Fig. 4. Surface plot for cutting force (Fc) Vs Feed, DOC

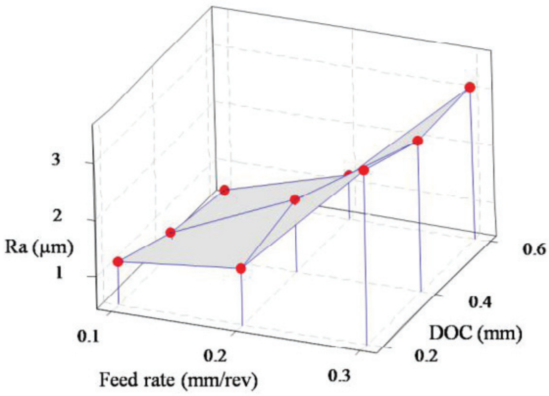
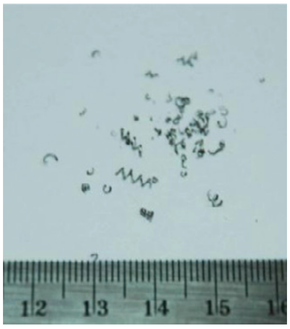


Fig. 5. Surface plot for Surface Roughness (Ra) Vs Feed, DOC

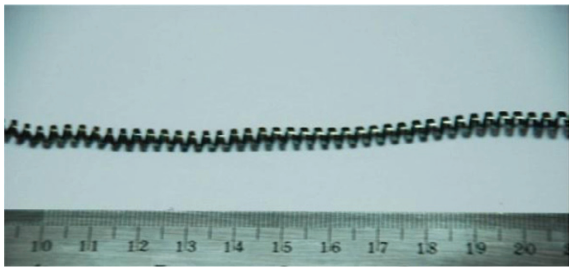
2.3 Chip formation

Both continuous and discontinuous chips were formed with spiral, curl and spring in shape. The photographs of the different chip morphology obtained are shown in Figure 6



(a)

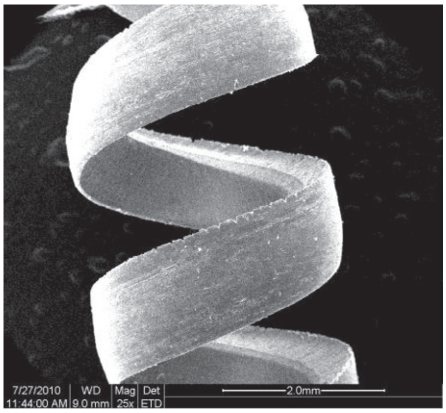
(b)



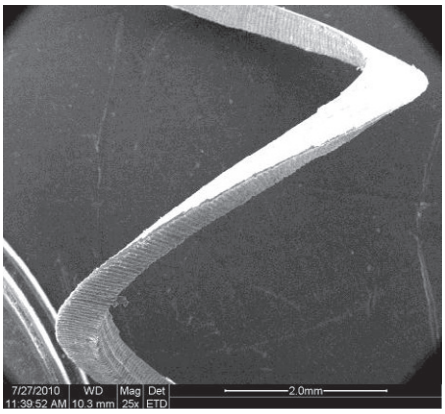
(c)

Fig. 6. Photographic images of chips formed for various cutting conditions (a) [60m/min,0.1mm/rev,0.2mm], (b) [100m/min,0.1mm/rev,0.6mm], (c) [60m/min,0.3mm/rev,0.6mm]

Figure 6(a) shows the chip morphology for optimum cutting condition and it is clearly evidenced that discontinuous chips are formed. This is due to lower feed rate with minimum depth of cut and where as figure 6(b) shows the chip for optimum surface roughness where the chips are continuous and spiral in shape. Figure 6(c) shows the chip formation for maximum cutting force (627 N) that is obtained for cutting condition 3, where the chips are found to be continuous and spring in shape.



(a)



(b)

Fig. 7. SEM Micrograph showing surface topography for (a) For cutting condition [60m/min,0.3mm/rev,0.6mm] (b) For cutting condition [60m/min,0.1mm/rev,0.2mm]

The scanning electron microscope images of chips are shown in figure 7(a) &7(b). For higher depth of cut with minimum feed rate the the chip formed are continuous and spring shape. If the depth of cut and feed rate are lowered for the same cutting speed discontinuous chips with spiral shapes are obtained.

Fig. 8. SEM Micrographs showing saw tooth formation in chips

The shear patterns and formation of saw tooth type is evidenced for cutting condition 3 and is shown in figure 8. The formations of chip for multiphase microalloyed steels are similar to the formation of chip for quenched and tempered steel [5].

2.4 Comparison of cutting forces

The cutting force obtained during machining multiphase microalloyed steel for different cutting speed is compared with AISI 4340 steel [7] for a depth of cut of 1mm with a feed of 0.2 mm/rev and is shown in figure 9. From figure 9 it is observed that AISI 4340 steel gives steady progressive reduction in force with various cutting speed.

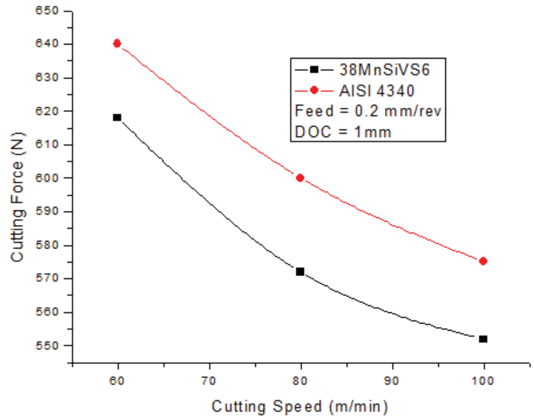


Fig. 9. Comparison of multiphase microalloyed steel cutting forces with AISI 4340

Whereas for multiphase microalloyed steel the forces comes down up to 80 m/min beyond that the forces are in increasing trend, this may be due to influence of tool wear.

The multiphase microalloyed steel with higher yield strength of 1384 MPa produce less force compared to AISI 4340. The easy machinability of microalloyed steel is promoted by soft polygonal ferrite (PF) and bainite present in the steel.

3. Conclusions

The influence of cutting parameters like cutting speed, feed rate and depth of cut on cutting force and surface roughness has been investigated and the following conclusions are drawn.

1. Feed rate influences more for cutting force (55.29 %) than depth of cut (39.66 %) and cutting speed (2.15 m/min) is insignificant.
2. For surface roughness the feed rate (90.16 %) influence more. The other two parameters such as depth of cut (5.32 %) and cutting speed (4.16 %) are insignificant
3. The multiphase microalloyed steel having a yield strength of 1384 MPa recorded less cutting force compared to existing high strength low alloy steel (HSLA). This shows better machinability for FBM steel
4. Chips formed are similar to the chips obtained during machining HSLA steel and saw tooth formation was observed for selected cutting condition.

References

[1] DeArdo A.J. Microalloyed Strip Steels for the 21st Century. *Mat Sci Forum* 1998; Vols.284-286;15-26

[2] Fourlaris G. Effect of vanadium alloying on the precipitation reactions during pearlite formation in medium and high carbon steels. *Mat Sci Forum* 1998; Vols.284-286;427-434

[3] Sankaran S, Sangal S, Padmanabhan K.A. Microstructural evolution and tensile behaviour of medium carbon microalloyed steel processed through two thermomechanical routes. *Mat Sci and Tech* 2005 Vol 21; 1152-60

[4] Yang W, Tarng Y. Design optimization of cutting parameters for turning operations based on the Taguchi method. J Mat Pro Tech 1998;84;122-29

[5] Ebrahimi A, Moshksar M.M. Evaluation of machinability in turning of microalloyed and quenched-tempered steels: Tool wear, statistical analysis,chip morphology. J Mat Pro Tech 2009; 209;910-921

[6] Cemal Cakir M, Bayram A, Kaan Kircali K, Ensarioglu C. Effects of microstructures on machinability of ductile iron. Proc.IMechE 2009 Vol 225;297-304.

[7] Lima J.G. Hard turning: AISI 4340 high strength low alloy steel and AISI D2 cold work tool steel. J Mat Pro Tech 2005;169; 388-395