Reinforcement of Tungsten Carbide Cutting Tool Properties via Cryogenic Treatment and Process Optimization

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The cutting tool performance is gradually increased and its tooling cost is through cryogenic treatment. More than 50% of cutting tool is improved by this process. Particularly the cross section and microstructure of the cutting tool is developed through cryogenic treatment. The substance properties of the cutting tool are improved by cryogenic treatment at deep freezing level. The hardness, strength and wear resistance of the cutting tool is enhanced. In this paper deals with the performance improvement such as surface finish, tool life and hardness of the tungsten carbide tool through cryogenic treatment. The process factor optimization was carried out by taguchi method.

Keywords: Cryogenic treatment; tool steel; substance properties; cutting tool; tool life

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The hardness and strength of the cutting tool was increased due to the presence of hard martensite formation after cryogenic treatment. Toughness and wear resistance was highly increased. The physical properties of the cutting tool and tool life were improved and metallurgical changes were attained [1-2]. The cutting performance was conducted on EN19 steel using cryogenic treated tungsten carbide inserts under different temperatures [3]. Phase transformation and new crystal formation was produced under cryogenic treated carbide tools [4]. The surface finish and flank wear resistance was enhanced using cryogenic treated tungsten carbide tools in cylindrical turning process [5-6]. The cutting tool performance was improved on cryogenic treated nano composite carbide tool. More than 20 percentages of material structure and grain refinement was developed in cryogenic treatment [7-8]. The cutting performance experiment was conducted on cast iron using cryogenic treated carbide tool and its outcome was compared to conventional tool [9]. The wear resistance of the cryogenic treated tungsten carbide was gradually enhanced during high speed milling operations at particular set of cutting conditions [10]. Taguchi parametric optimization was carried out on the effects of deep cryogenic treated tungsten carbide cobalt based insert on turning process of aluminium [11].

The present paper is discussed about tungsten carbide cutting tool performance improvement through cryogenic treatment. The process factor was optimized through Taguchi approach.

MATERIALS AND METHODS

Titanium based alloy which consist of nickel and chromium was considered as the work material. The alloy contains 78% of titanium, 10% of nickel, 10% of chromium and 1% of vanadium and 1% of aluminum. These composition of titanium based alloy was synthesized through stir casting method. It has high strength and hardness. It was used in aerospace and chemical industries. The cutting tool life was improved through realigning the molecular structure in cryogenic treatment. Line diagram of cryogenic treatment process was shown in fig.1. The cryogenic treated tungsten carbide tool was used to cut the titanium alloy and it was processed under -190°C. Brushless DC motor was selected for tool speed. In this process, the tungsten carbide tool was slowly cooled in cryo processor using liquid nitrogen. This slow cooled down cryogenic temperatures helps to avoid the stress formation on the material. Then, the material was allowed at freezing temperature up to one day followed by tempering process.

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During this process, the crystal structure was converted in to martensite. The retained austenite structure also completely converted to martensite. Hence, the consistent of grain structure and durability of the alloy was enhanced.

RESULT AND DISCUSSION

The dimensional accuracy of the tool was greatly improved at cryogenic temperature. Titanium based alloy was cut by tungsten carbide tool with different process factor such as tool speed, feed and depth of cut. Tool dynamo meter was utilized to measure the cutting forces. The cutting performance of tool is given in the table 1. From this table, the minimum cutting force was attained at maximum of tool speed and depth of cut. The optimal cutting force was found in inconel alloy using cryogenic treated tungsten carbide tool [12].

TAGUCHI METHOD

Taguchi approach was utilized to found the optimal cutting force with respect to the input constraints. The quality characteristics of the cutting parameters were depending on SN ratio. L9 based experimental design was used to evaluate the optimal cutting force. The smaller the better criterion was considered for the cutting force to increase the tool life. The optimal level of cutting process factor was determined through SN ratio [13]. The parametric combination and its response were mainly depending on variance analysis, SN ratio and orthogonal array [14].

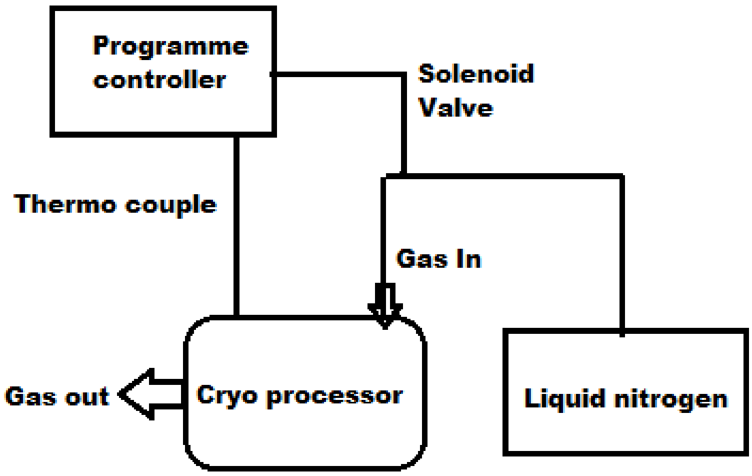

Figure 1. Line diagram of cryogenic treatment.

Table 1. Cutting performance of tool.

S.No	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)	Cutting force (N)
1	25000	2	3	0.34
2	25000	4	6	0.36
3	25000	6	9	0.33
4	30000	2	6	0.31
5	30000	4	9	0.30
6	30000	6	3	0.32
7	35000	2	9	0.28
8	35000	4	3	0.29
9	35000	6	6	0.26

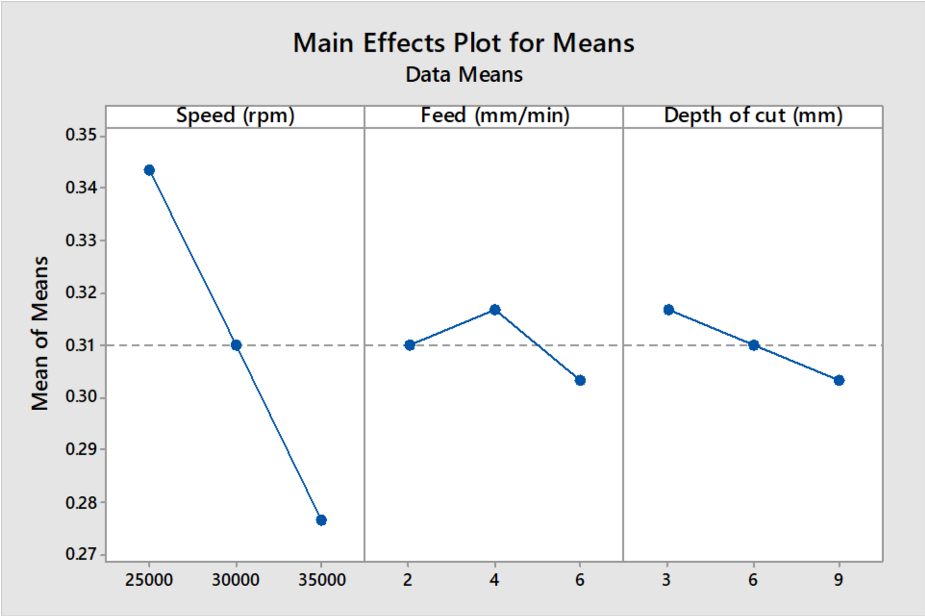

Figure 2. Response of SN ratio.

Table 2. Variance analysis on tensile strength of the lost foam casting.

Source	DF	SS	MS	F	P	%
Speed	2	0.006667	0.003333	11.11	0.083	86.57
Feed	2	0.000267	0.000133	0.44	0.692	03.46
Depth of cut	2	0.000600	0.000300	0.32	0.561	07.79
Error	2	0.000167	0.000121	--	--	02.18
Total	8	0.007701	--	--	--	100

The response of the signal to noise ratio was shown in Figure 2 based on the level of input constraints. The optimal cutting force was attained at speed of 35000 rpm, feed of 6mm/min and depth of cut of 9 mm. The contribution of each input constraints on cutting force was shown in Table 3. The tool speed was the most predominant factor on cutting force. It has developed 86.57% of effect on cutting force. The second dominant factor was depth of cut which has produced 7.79% of effect on cutting force. The tool speed was the powerful factor which was concluded from variance analysis and the effect of cryogenic cooling on tool life was investigated in titanium alloy [15-16].

The generated mathematical model was used to predict the optimal cutting force with respect to the input constraints A, B and C. Here, A, B and C were speed, feed and depth of cut respectively. The developed mathematical model was depends on the level of the input constraints and design of the experiments [17]. The claim for better tool performance and reduced downtime made promising by means of cryogenically treated tungsten carbide tools is accompanied by production efficiency gains through set production and FMS integration, as shown in conventional batch systems [18-19].

Cutting force (N) = 0.31000 + 0.03333 A-25000 - 0.00000 A-30000 - 0.03333 A-35000 + 0.00000 B-2+ 0.00667 B-4 - 0.00667 B-6 + 0.00667 C - 0.03000 C-6 - 0.00667 C-9.

The most influential factor such as speed has produced largest effect on cutting force. From the Figure 3, the minimum cutting force was attained at maximum speed and moderate depth of cut. The maximum level of cutting force was not suitable to cut the material. The maximum cutting force was developed at minimum level of tool speed.

The contour plot of cutting force between feed and speed was shown in Figure 4. More than 0.35N of cutting forces were attained at feed of 3-5 mm/min and speed of 25000 rpm. The minimum cutting force was required at feed of 6 mm/min and speed of 35000rpm.

The contour plot of cutting force between depth of cut and speed was shown in Figure 5. More than 0.35 N of cutting forces were attained at depth of cut of 4-7 mm and speed of 25000 rpm. The minimum cutting force was required at speed of 35000 rpm.

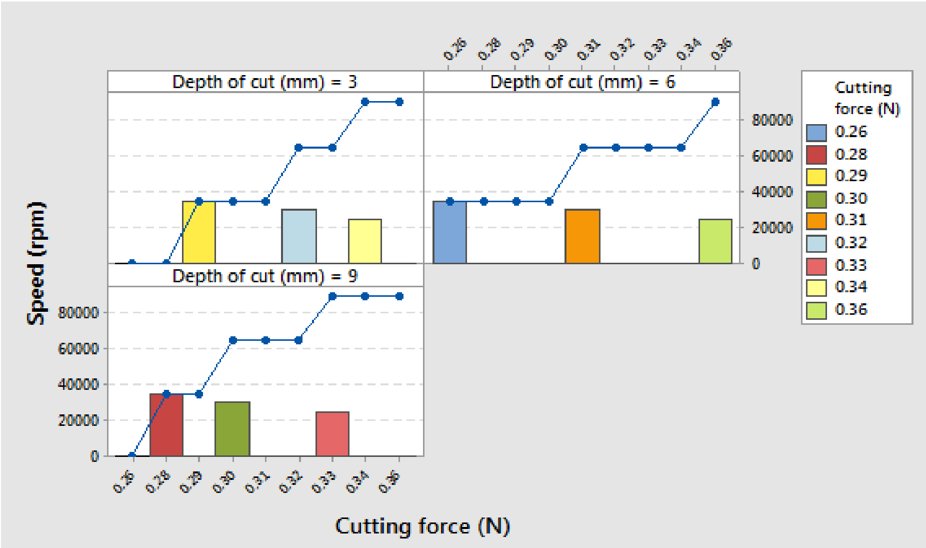

Figure 3. Pareto chart analysis of cutting force.

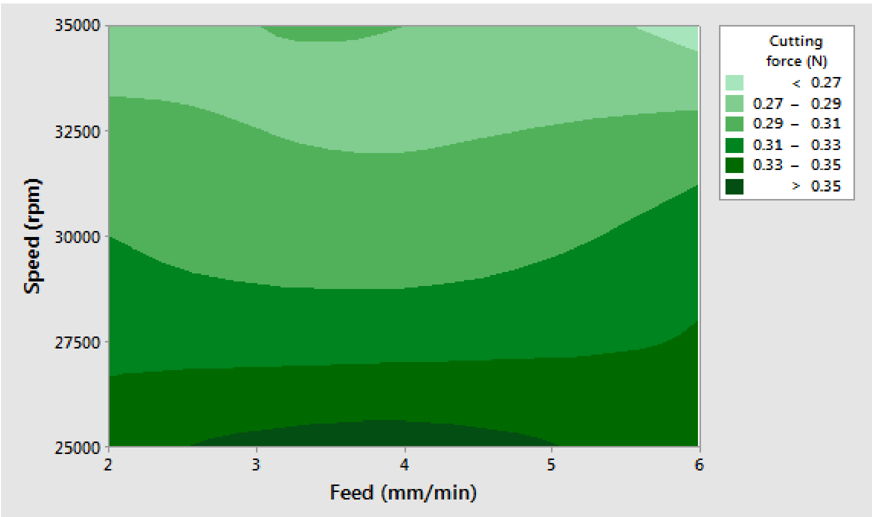

Figure 4. Contour plot between feed and speed.

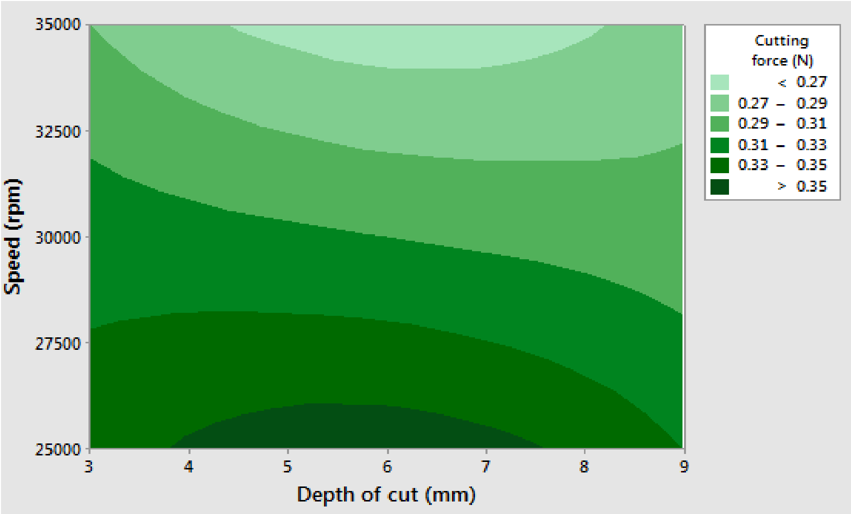

Figure 5. contour plots between depth of cut and speed

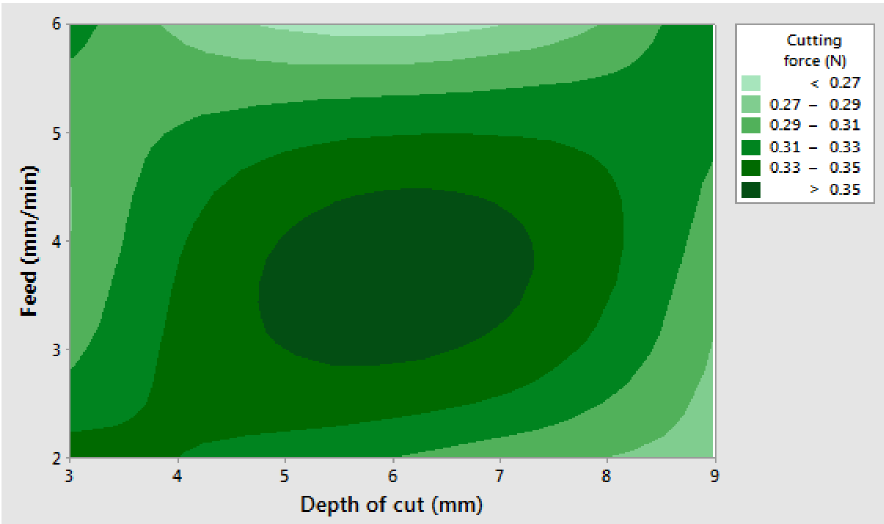

Figure 6. contour plots between depth of cut and feed.

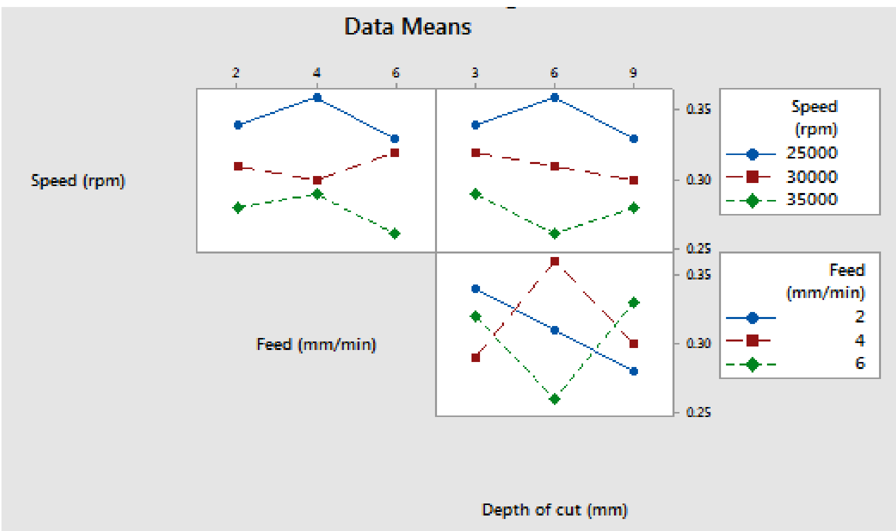

Figure 7. Interaction plot for cutting force.

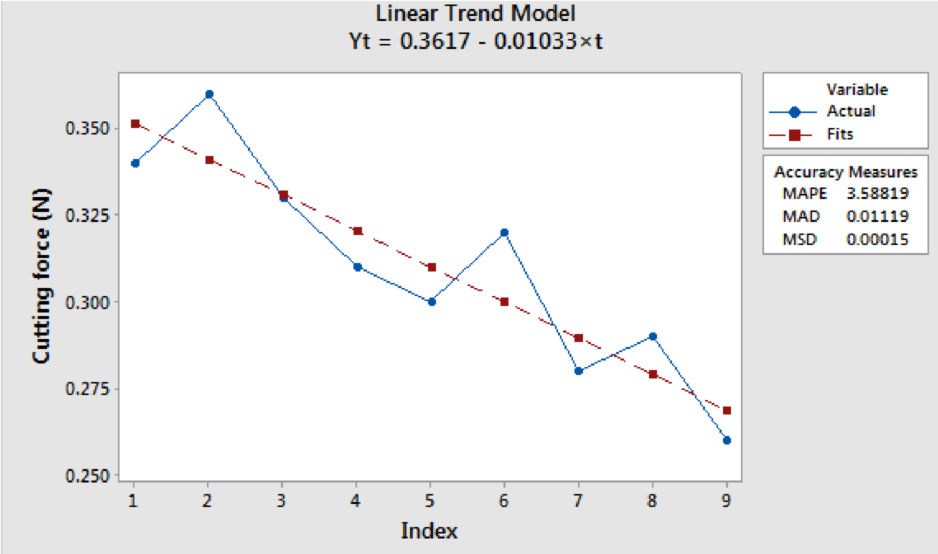

Figure 8. Trend analysis of cutting force.

Interaction plot for cutting force was revealed in Figure 7. The regular variation was attained between input and output constraints of the cryogenic factors and responses. The cutting force was decreased at speed of 2500 rpm. Simultaneously, the cutting force was decreased at feed 4mm/min.

Trend analysis of cutting force was shown in Figure 8. The variation of cutting force with respect to the change of input constraints of the cryogenic treatment. At the starting of the experiment, the cutting forces were gradually reduced. At the same time, fluctuations were occurred at middle of the experiment due variation of microstructure and hardness of the material.

CONCLUSIONS

According to the cutting tool performance based on the cryogenic treatment and its process optimization, the following points were considered in conclusion. The cutting performance of cryogenic treated tungsten carbide tool was conducted on titanium based alloy. The optimal cutting force was attained at speed of 35000 rpm, feed of 6mm/min and depth of cut of 9 mm. Speed of the tool has developed 86.57% of effect on cutting force followed by depth of cut which has produced 7.79% of effect on cutting force. The correlation between the input and output constraints were analyzed through contour plot.

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