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PERFORMANCE EVALUATION OF UNCOATED TUNGSTEN CARBIDE TOOL IN TURNING AISI 1040 STEEL AT LOW TEMPERATURE

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Abstract In this paper, the performance of an uncoated tungsten carbide insert (SNMG 120408 TTS;P30 ISO specification; Wadia) was investigated during turning of AISI 1040 steel. The PSBNR 2525 M12 tool holder was used. Cutting tests were performed with constant depth of cut and at various cutting speeds and feed rates to investigate the performance of the tool under dry and cryogenic cooling conditions. The chips produced by the insert during experimental trials were examined to determine the secondary shear zone, chip thickness (a_2), chip reduction coefficient (ζ) and chip contact length. The tool performs best under cryogenic cooling conditions, as lower cutting forces, very good surface finish could be obtained and chips with lowering the chip thickness (a_2) could be produced that contributed to low chip strain and therefore to low residual stresses on the work piece as compared to dry condition.

Keywords: Low temperature, Cutting forces, Surface roughness, Chip

INTRODUCTION

Machining at room temperature is the most convenient process of producing components. Lots of theoretical and experimental results are available on machining at room temperature. Several researches have also attempted hot machining process [*Kainth and Chaturvedi, 1975, Kainth et al, 1978*]. Machining of high strength heat resistant (HSHR) metals and alloys become easy due to considerable reduction in cutting forces at high temperature.

Temperature rise during the cutting operation is the main cause of tool wear. At higher speed, tool wear become very significant and adversely affect the product quality as well as production rate. Alloys with low thermal conductivity put-up-stiff challenge before a production engineer. Despite the use of cutting fluid, premature failure of cutting tool occurs [*Paul et al, 2000*]. At high temperature, metal become ductile, hence built-up-edge (BUE) is formed which increase surface roughness [*Paul et al, 2000*]. At the low temperature, metal becomes harder and shear angle will increase as expected. Due to above reasons, the cutting forces and surface roughness may decrease. As from the studies of the properties of materials, at low temperature bcc and hcp metals become brittle and fracture toughness of metals reduce. It means brittle fracture of metal may be obtained at lower temperature.

Very limited numbers of researches have attempted to improve the cooling capacity of air by refrigerating it [*Shaw, 1984*]. Olson (1948) using cool air in milling operation, reported 400% increase in tool life over air at room temperature. Pahlitzch found an improvement in tool life over air by 150% using Co_2 and 240% using nitrogen. Dramatically increment in tool life and reduction in cutting time was reported [*Annon,1973, Sitting*] by spraying Ferron-12 into the clearance space between the work and tool. Metal and alloy machined with greater easy while using subzero coolant [*Filonenko and Slobodyanik, 1975*]. A study was made on surface finish and hardening of work pieces made of stainless steel and titanium alloy while cutting with cemented carbide tools. It was established that surface finish improves as the temperature decreases [*Dhar et al, 2001, 2000*]. Significant improvement in chip formation mechanism and reduction in specific energy requirement, grinding temperature and residual stress were observed in grinding with cryogenic cooling when compared with grinding dry and soluble *oil [Dhar and Chattopadhyay, 2000*].

EXPERIMENTAL DETAILS

Cutting test were carried out on a 11 kW NH22 HMT (India) lathe machine under dry and cryogenic cooling conditions. The tool was tested at the cutting speeds (V_c) of 66, 85, 110 and 144 m/min and feed rates (S_o) of 0.12, 0.16, 0.20 and 0.24 mm/rev. A depth of cut (t) of 1.5 mm was used for near net shape manufacturing and was kept constant throughout the tests.

Commercially available uncoated tungsten carbide having geometry designated by ISO as SNMG 120408-26 with working tool geometry -6,-6,6,6,15,75,0.8 (mm) was tested. The insert was rigidly mounted on a right hand style tool holder designated by ISO as PSBNR 2525 M12.

The cutting performance tests were performed on AISI 1040 steel bar. Based on the AISI SAE standard carbon steel; table, it is a non-resulphurised grade steel and its composition is 0.41%C, 0.700%Mn, 0.040%P and 0.050%S. The hardness of the bar was measured and found to be 180 BHN. The work piece material used has a dimension of 750 mm in length and 200 mm in diameter.

The cutting performance tests involved 16 trials. The response variables measured were the cutting forces (main cutting force, P_Z and feed force, P_X) and the surface roughness. The cutting forces were measured using 3-D dynamometer (Kistler, Type:9257B), a multi channel charge amplifier (Kistler, Type:5007) and a data acquisition systems. The surface roughness of the turned surface was measured using a portable surface roughness tester (Talysurf, surtronic 3P, Rank Taylor Hobson limited). The chip produced during each trial were collected, mounted onto specimen holder, ground, polished and eatched. These were then observed using a Olympus inverted metallurgical microscope (model: MG Japan).

RESULTS AND DISCUSSION

Cutting forces: The main cutting force (P_Z) and feed force (P_X) versus cutting speed (V_c) relationships for the various experimental trials were shown in Fig.1 and Fig.2 respectively. The figures also showed the effect when different environments and feed were used. The nature of variation in the cutting forces P_Z and P_X observed during turning the AISI 1040 steel rod by the SNMG inserts at different V_c and S_o under both dry and cryogenic cooling conditions are shown in Fig.1 and Fig.2 respectively.

The magnitude and pattern of the cutting forces is one of the most important machinability indices because that plays vital roles on power and specific energy consumption, product quality and life of the salient numbers of the Machine-Fixture-Tool systems. Design of the Machine-Fixture-Tool-Work systems also essentially need to have the knowledge about the expected characteristics of the cutting forces. Therefore, it is reasonably required to study and assess how the cutting forces and tool life are affected by cryogenic cooling with liquid nitrogen which is primarily aimed at environment friendly machining.

Fig.1 and Fig.2 are clearly showing that both P_Z and P_X have uniformly decreased with the increase in V_c more or less under all the feeds, for both the tools and environments undertaken as usual due to favourable change in the chip-tool interaction resulting in lesser friction and intensity or chances of built-up edge formation at the chip-tool interface. In machining ductile metals like steels by carbide tools, which are not chemically inert like ceramics, the chip material under elevated temperature and high pressure sticks in their layer on the tool surface by adhesion and diffusion and often resulting in gradual piling of the strain hardened layers forming built-up edge near the cutting edge. After growing to certain size, the built-up edge gets separated from the tool by the increased transverse force. Both the formation and frequent separation of built-up edge are detrimental because it not only raises and fluctuates the cutting forces but also impairs the finished surface and reduces tool life.

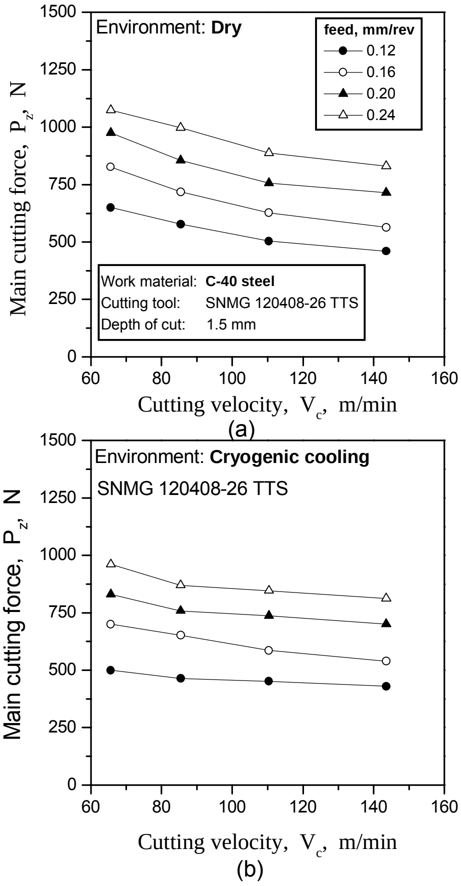


Fig. 1 Variation in P_Z with that of Vc and So in machining C-40 steel by SNMG insert under dry and cryogenic conditions

It is evident from Fig.1 and Fig.2 that both P_Z and P_X decreased sizeably due to application of liquid nitrogen jet more or less at all the V_c-S_o combinations and for both the inserts. This improvement can be reasonably attributed to reduction in the cutting temperature particularly near the main cutting edge where seizure of chips and formation or tendency of formation of built-up edge is more predominant. In this respect, the liquid nitrogen jet impinged along the main cutting edge seems to be more effective in cooling the neighbourhood of the main cutting edge.

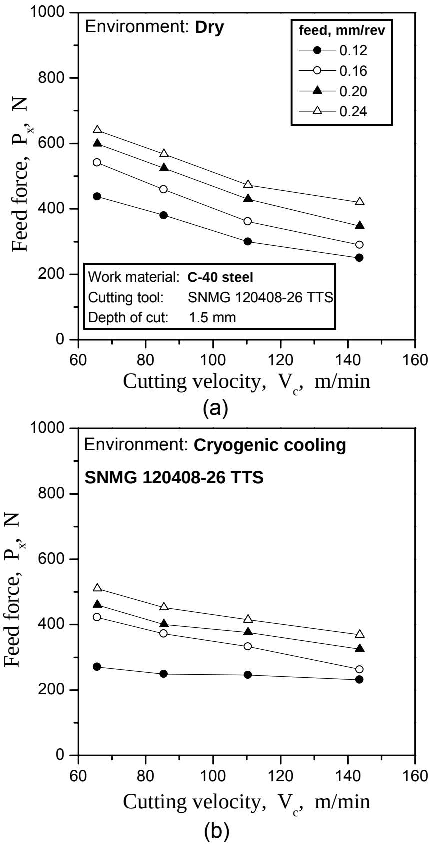


Fig. 2 Variation in P_X with that of V_c and S_o in machining C-40 steel by SNMG insert under dry and cryogenic conditions.

During machining, the shear strength of the ductile type work material at the cutting zone in one hand increases due to compression and straining and on the other hand decreases due to softening by the cutting temperature if it is sufficiently high. But again along with softening, the chip material becomes sticky for which the friction force and hence the cutting force may tend to increase. The overall effect of all such factors on the magnitude of the cutting forces will depend on the nature of the work material and the level of the cutting temperature. Therefore, it seems that cryogenic cooling had ultimately favourable effect on the behaviour of the present alloy steel in respect of cutting forcers for which cryogenic cooling enabled reduction in the cutting forces to some extent even when built-up edge was not visible.

The percentage reduction observed in P_Z and P_X due to cryogenic application during turning the present steel by the SNMG and SNMM inserts at different V_c and S_o are given in Table-1. The table shows that there is no definite trend in the role of variation in V_c and S_o as well as the type of inserts on the percentage reduction in P_Z and P_X unlike on that in cutting temperature. The degree of reduction in the cutting forces seems to have been governed combinedly by the levels of V_c and S_o and the tool geometry, which together not only controlled the degree of cooling by the liquid nitrogen jets but also influenced the indirect effects of cryogenic cooling like reduction in chip-tool contact length, break-in wear at the cutting edges, close curling of the chips, all of which might have contributed in reducing the cutting forces. The randomness in percentage reduction in P_Z and P_X(Table-1) might be also indebted to the random formation and dislodgement of the built-up edge, whatever be its size and bond strength. However, more indepth study is needed to explore the actual role of the different parameters on the effect of cryogenic cooling in machining different materials by different tools.

Table 1:Reduction in forces, θ_{avg}, chip reduction coefficient and friction coefficient due to cryogenic cooling in turning C-40 steel by SNMG inserts

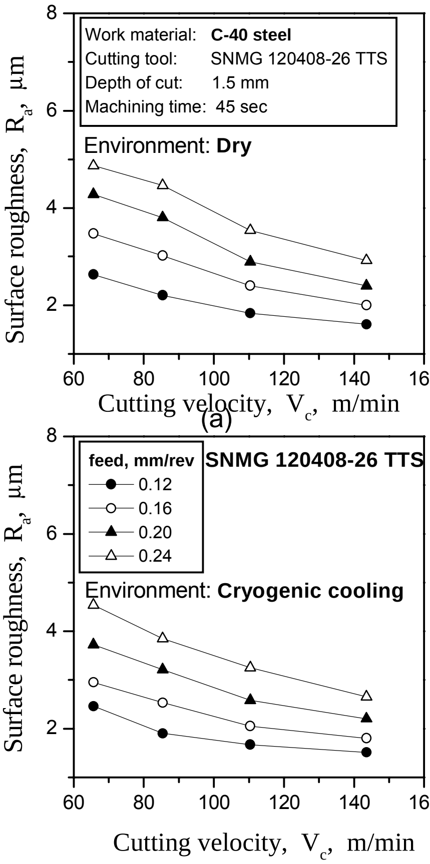
$V_{c,}$, m/min	S_o rev/min	Percentage reduction in				
		P_Z	P_Z	θ_{avg}	ζ	μ
66	0.12	38.40	23.10	27.50	16.0	21.8
85		34.50	19.70	25.50	13.6	20.4
110		18.00	10.30	20.70	10.5	10.4
144		7.60	6.52	15.00	6.25	4.40
66	0.16	22.00	15.30	19.30	19.4	7.50
85		19.00	9.19	19.40	16.4	11.5
110		7.80	6.69	16.90	12.5	6.50
144		9.30	4.26	13.80	9.76	10.0
66	0.20	23.20	14.90	16.50	18.3	13.7
85		23.50	11.30	16.20	16.9	12.5
110		12.60	2.65	15.00	15.8	9.10
144		6.30	2.10	14.50	8.33	5.10
66	0.24	20.30	10.60	15.70	16.7	12.5
85		20.30	12.80	16.90	14.3	8.90
110		12.30	4.73	16.70	12.9	9.50
144		12.10	2.17	15.40	11.1	12.5

Surface roughness: The surface roughness measurements obtained from the various experimental trails were shown in Fig.3. Classical surface roughness related equation [*Shaw, 1984*]:

$$h_m = S_o^2/8r$$

where h_m is the peak value of roughness caused due to feed marks. S_o is the feed rate and r is the nose radius, show that surface roughness is primarily dependent on feed rate and the tool nose-radius. These equation gives ideal surface finish values which can only occur when satisfactory cutting conditions are achieved. The value of surface roughness increases sharply with the increase in feed and decrease with increase in V_c. Built-up edge (BUE) formation and vibration worsen the surface further. However, deterioration of the nose and the auxiliary cutting edge due to chipping and abrasion wear at the tool nose aggravates the surface roughness.

The results shown in Fig.3 indicate that surface roughness increased substantially with the increase in feed when machined by SNMG insert and under both the environments. This can be attributed mainly to the roughness caused by the feed marks as explained earlier. It is also noted that surface roughness decreased to some extent with the increase in V_c possibly due to smoothening of the nose profile by adhesion and diffusion types wear.



(a)

(b)

Fig. 3 Variation in surface roughness observed after turning C-40 steel by sharp SNMG insert at different V_c and S_o under dry and cryogenic conditions.

However, incase of both the tools surface roughness decreased to some extent though in different degree at different V_c and S_o when the job was machined under cryogenic cooling. This can be attributed to reduction in auxiliary flank wear due to retention of tool hardness through reduction in temperature by the liquid nitrogen jet specially that impinged along the auxiliary cutting edge.

Chips: The pattern of chips in machining ductile metals are found to depend upon the mechanical properties of the work material, tool geometry particularly rake angle, levels of V_C and S_O, nature of chip-tool interaction and cutting environment. In absence of chip breaker, length and uniformity of chips increase with the increase in ductility and softness of the work material, tool rake angle and cutting velocity unless the chip-tool interaction is adverse causing intensive friction and built-up edge formation.

Table 2(a):Shape and color of chips of C-40 steel at lower feeds while machining by SNMG inserts.

V_c m/min	Env.	Feed, S_o, mm/rev			
		0.12		0.16	
		Shape	Color	Shape	Color
66	Dry	half turn	light blue	half turn	bluish gray
	Cryo	spiral	metallic	half turn	metallic
85	Dry	spiral	bluish	half turn	blue
	Cryo	spiral	metallic	half turn	metallic
110	Dry	ribbon	deep blue	half turn	deep blue
	Cryo	half-turn	metallic	half turn	metallic
144	Dry	spiral	burnt blue	half turn	burnt gray
	Cryo	helical	metallic	half turn	metallic

Table 2(b):Shape and color of chips of C-40 steel at higher feeds while machining by SNMG inserts

V_c m/min	Env.	Feed, S_o, mm/rev			
		0.20		0.24	
		Shape	Color	Shape	Color
66	Dry	helical	bluish gray	half turn	gray & blue
	Cryo	helical	golden	spiral	golden
85	Dry	helical	bluish gray	half turn	gray & blue
	Cryo	helical	golden	half turn	golden
110	Dry	helical	deep blue	half turn	deep blue
	Cryo	helical	golden	half turn	golden
144	Dry	helical	burnt blue	ribbon	deep blue
	Cryo	helical	golden	half turn	golden

Table-2(a) and Table-2(b) show that the C-40 steel, when machined by the pattern type SNMG inserts under dry condition produced ribbon type continuous chips at low feed (0.12 mm/rev) and more or less half turn chips at higher feeds. The geometry of the SNMG insert is such that the chips of this softer steel (C-40 steel) first came out continuously, got curled along normal plane and then hitting at the principal flank of this insert broke into pieces with regular size and shape. When machined under cryogenic cooling the form of these ductile chips did not change appreciably but their back surface appeared much brighter and smoother. This indicates that the amount of reduction of temperature and presence of inert nitrogen due to cryogenic application enabled favorable chip-tool interaction and elimination of even trace of built-up edge formation. The color of the chips have also become much lighter i.e. metallic or golden from blue or gray depending upon V_C and S_O

due to reduction in cutting temperature by cryogenic cooling.

It is important to note in Table-2(a) and Table-2(b) that the role of cryogenic cooling has been more effective in respect of form and color of the chips when the same steel was machined by the groove type SNMG inserts. Such improvement can be attributed to effectively larger positive rake of the tool and better cooling by the jets coming along the groove parallel to the cutting edges.

Almost all the parameters involved in machining have direct and indirect influence on the thickness of the chips during deformation. The degree of chip thickening which is assessed by chip reduction coefficient, ξ, plays sizeable role on cutting forces and hence on cutting energy requirements and cutting temperature.

CONCLUSIONS

The following conclusions could be made on the basis of investigation carried out:

1. Cutting forces reduces
2. Chip-tool interface temperature decrease
3. Chip reduction coefficient decrease
4. Surface roughness decreases
5. Curling of chip decreases

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