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Effect of Machining Parameters on Cutting Force , Tool Wear and Surface Roughness of AISI 304 Austenitic Stainless Steel – A Review

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Abstract : In this review study, the effect of important parameters of machinability like material removal rate, cutting force and surface roughness were studied. Evaluation of efficiency is based on certain process variable such as flank wear, surface roughness on the work piece, cutting forces developed, temperature developed at the tool chip interface are studied. The optimum cutting speed the impact of cutting speed and cutting fluids on tool wear and surface roughness have been studied during turning an AISI 304 austenitic stainless steel using cemented carbide cutting tools. The studies have been proved that tool wear and surface roughness decreases with the increase in the cutting speed.

Keywords: Speed, Feed,Depth of cut,Cutting Fluid, Surface Roughness, Turning, Optimization, Fuzzy Logic, AISI 304.

INTRODUCTION

Austenitic stainless steels have a high work hardening rate , low thermal conductivity , high corrosion resistance, High strength, high built-up-edge(BUE) tendency, and high deformation hardening. These are the main factors that make their machinability difficult. These factors are responsible for the poor machinability of austenitic stainless steels. Also during cutting they form very strong bond with the cutting tool during cutting . During cutting when chip is broken away, it may bring fragment of tool, particularly when machining with cemented carbide tools. operators encounter problems like poor surface finish and tool failure due to high temperature at tool–work piece interface during machining of AISI 304 . In this study, turning tests were carried to determine the optimum machining parameters i.e best cutting speed and feed rate were according to flank wear,Buil up edge (BUE), chip form, surface roughness of the machined samples and machine tool power consumption.

Tables 1. chemical composition of AISI 304

C	0.05487
Si	0.64
Mn	1.66
Cr	18.2
Ni	9.11
Mo	0.092
Cu	0.14
Ti	0.006
V	0.046
W	0.048
Co	0.040
Nb	0.013
Pb	0.015
Fe	69.7

Table 2. Typical Physical and Thermal Properties of AISI304

PARAMETER	UNIT	VALUE
DENSITY	Kg/m^3	8000
ELASTIC MODULUS	GPa	193
POISSIONS RATIO	-	0.3
Coefficient of thermal expansion	$Mmm^{-1}\ C^{-1}$	17.8
Thermal Conductivity	W/mK	16.2
Specific heat capacity	J/kgK	500

LITERATURE REVIEW

Many attempts have been made to improve the machinability of austenitic stainless steels (O'Sullivan and Cotterell, 2002) [1]. Problems such as poor surface finish and high tool wear are common in machining of austenitic stainless steel (Kosa, 1989) [2]. Ihsan et al. (2004) carried out turning tests on AISI 304 austenitic stainless steel to determine the optimum machining parameters.

Zafer and Sezgin (2004) [3] determined the best suitable cutting condition for machining considering the acoustic emission during the cutting process of AISI 304 stainless steels. Korkut et al. (2004) [4] investigated the influence of cutting speed on surface roughness, chip characteristics and tool wear during turning of AISI 304 steel. Tekiner and Yeşilyurt (2004) [3] utilized unique process sound technique to determine optimal condition in order to achieve favourable chip form and minimum flank wear, built-up edge and Ra. Noordin et al. (2001) determined that the surface roughness is dependent on the feed rate therefore by lower feed rate produced better surface finish. It was also determined that the obtained Ra value increased with increase in cutting speed. Xavior and Adithan (2009) [5] studied the influence of different cutting fluids on the tool wear and Ra value during turning. It was observed that coconut oil performed best. Asibu (1985) [6] found that flank wear changes the mechanics of the cutting process, induce chatter and changes in the final dimension of the product. Flank wear is used as the criteria in determining the tool life (Byrd and Ferguson, 1978) [7]. Flank wear may be due to adhesive wear or abrasive wear caused by the hard second phases in the work material (Ramalingam and Wright, 1981) [8]. The presence of the large unstable BUE causes poor surface finish. Wear at the tool cutting edge directly influences the machined surface roughness since the edge is in direct contact with the newly machined surface (Ezugwu and Kim, 1995) [8].

CUTTING FLUID

Lubricants are commonly used in all type of industry for cooling and to lubricates the tool and work-piece interface in order to improve machinability. Cutting fluids have been used in the machining process with the purpose to improve tool life, improved surface finish, improved dimensional accuracy, reduced cutting force and reduced vibrations (De chiffre, 1988) [9] of the work piece–tool–chip system. Coolants for machining was first used by Taylor in 1907, who gained a 40% increase in cutting speed when machining steel with high speed tools using water as coolant (Taylor, 1907) [10]. Cutting fluids provide lubrication between the work piece and tool and also remove heat generated during the cutting process (De Chiffre et al., 1988) [9].

Vegetable-based cutting fluids:

Cutting fluids based on mineral oils are traditionally used in production shops due to their chemical stability and frequent reuse. However, nowadays use of new types of cutting fluids are based on vegetable oils and esters in machining is defined by their higher biodegradability and lower environmental impact. Emulsions of vegetable oils were prepared using ionic and non-ionic surfactants for use as metal working fluids. The use of vegetable oil in metal working applications may reduce problems faced by workers, such as skin cancer and inhalation of toxic mist in the work environments. Jacob et al. (2004) created a vegetable-based emulsion that can be used in the metal working industry to replace partially or completely the commonly used petroleum based emulsions. Vegetable oils have good lubricating ability and have been used for the formulation of metal cutting emulsions (Herdan, 1999) [11]. Recent research was also done on the vegetable oil-based emulsion to produce stable emulsions to be used as metalworking fluid and other application(Alander and Warnheim, 1989) [12]. Rape seed was used by Ioan et al. (2002), in his experiment, and shows that lubricating capacity of rape seed oil compared to that obtained for a usual mineral oil. Cutting fluids based on vegetable oils showed better performance than mineral oils. All type of vegetable-based oils have given the better results than the commercially available mineral oil by improving of tool life and reduction in thrust force.

Coconut oil

Coconut oil belongs lauric oils which is a unique group of vegetable oils. Chemical composition of coconut oil is lauric acid (51%), myristic acid (18.5%), caprilic acid (9.5%), palmitic acid (7.5%), olcic acid (5%), capric acid (4.5%), stearic acid (3%) and linoleic acid (1%). The saturated character of the oil imparts a strong resistance to oxidative stability. It can been said that coconut oil shows better oxidative stability in comparison to other vegetable oils with high percentage of unsaturated fatty acid content. Coconut oil shows comparatively lesser weight gain under oxidative environment among the vegetable oils considered.

METHODOLOGY

During the experiment, a round bar of AISI 304 stainless steel of diameter 60 mm and length 200 mm was machined. AISI 304 was used as the work material and Sandvik’s carbide CNMG 12 04 08 insert was used as the cutting tool. The inserts were clamped mechanically on a rigid tool holder. After the machining process, the insert was removed and its flank wear was measured using Mitutoyo’s Tool Maker’s microscope. To grasp the knowledge of the tool wear, the microscopic picture of inserts were observed using Carl Zeiss optical microscope, with the magnification range of 500×. The average surface roughness on the work piece was measured using Mitutoyo’s Surf test surface finish measuring instrument. The experimentation for this work was based on Taguchi’s design of experiments (DOE) and orthogonal array. A number of experiments have been carried out with the increase in the number of the process parameters. Taguchi method is used to solve the problem, which utilizes the special design of orthogonal arrays to study the entire parameter space with a small number of experiments. Three cutting parameters namely, cutting speed, depth of cut and feed rate were considered for experimentation, in this work. Apart from this type of cutting fluid is also considered as one of the critical input parameters while designing the experiments. Accordingly there are four input parameters and for each parameters three levels were assumed. The response obtained from the trials conducted as per L27 array experimentation was recorded and further analysed. Cutting fluid is the parameters which does not have any quantitative levels but each oil is being considered as one level for experimentation

Chip formation

120 m/min: Chip curl radii of about 1–1.25 mm (small radius) and a chip thickness of about 0.6 mm, most of chip have this parameter. The rest of the chipss radii have parameter of around 3–3.5 mm and chip thickness were to be 0.4 mm. The chips colour is close to yellow.

150 m/min: With this cutting speed, chip curl shows very less variation in radii, as that was observed at 120 m/min cutting

speed. Chip curl radii were around of 2.5–3 mm and chip thickness to be around 0.4–0.5 mm, in this case. The chips colour were brighter than that produced at 120 m/min cutting speed.

180 m/min: Consider, the chip curl radii to be homogeneous. Chip curl radii and chip thickness were of around 6–7 mm and 0.4 mm, respectively, for this speed. Chip colour matches with the workpiece materials colour.

Tool-chip contact length shows the shiny areas on the tool rake face, which is decreased with increase in the cutting speed. Chip curl radius and chip thickness very much relate the cutting speed at which the machining is performed. Low cutting speed have chip curl of small radius and large chip thickness. With the increase in cutting speed, chip curl radius increase and chip thickness decrease stepwise. The effect of heat on the thicker chips with small curl radii is as explained. Firstly, the thick chips with small curl radii have less surface area than those with small thickness and large curl radius. This shows low efficient of heat dissipation, when the chips are in contact with the tool. Secondly, tool-chip with maximum contact length on the tool rake face was observed at 120 m/min cutting speed. Finally, with cutting speed of 120 m/min thick chips with small curl radii formed , shows that chips remained in contact with the tool for longest duration at the lowest cutting speed than that at higher cutting speeds. Thus, this leads to more friction between the chip and the tool. However, with increasing the cutting speed to 150 m/min, chips curl radii increased and thickness decreased. Thus, the chips becomes more brighter in colour than that obtained at 120 m/min. Further increasing the cutting speed to 180 m/min, the chips became similar in colour to the work piece materials. Thus it can be said that least influence of heat is observed at this cutting speed for the chips having the large curl radii and small chip thickness, compared to the others type of chips.

TOOL WEAR AND SURFACE ROUGHNESS

Influence of heat over the cutting tool is responsible for the low performance of the tool at the lower cutting speed. The reason for this is that generation of large amount of heat during metal cutting and in the machining of AISI 304 stainless steel, it doesn't dissipate heat rapidly due to the low thermal conductivity of this material. The heat generation occurs in three areas: the shear zone, rake face and at the clearance side of the cutting edge. As is explained above, it was deduced from the chips colour, which is the most obvious indication of temperature of steel chips, that the chips formed at lower cutting speed (120 m/min) were affected mostly from the heat. Thus, have the highest temperature in comparison to the others. Also, contact with the tool on the rake face is for the longest time, as the maximim tool-chip contact length was observed at 120 m/min cutting speed on the tool rake face. Impact of low cutting speeds, is contact time increased on the rake face as the chips movement are slower in comparison to the higher cutting speeds. Thus it can be concluded that with longer contact time of rake face and the high chip temperature, rise the thermal softening of the tool by the low conductivity of the heat from the chips to the tool. There by, reduces wear resistance of the tool. Surface roughness values (Ra) were also found to decrease with increasing cutting speed. It is known that the type of chip produced during the machining operation has a significant effect on the surface finish. As chip thickness can be related to shear plane angle, cutting force requirements also changes depending on the chip thickness and also does the vibration. In this study, chip thickness and chip curl radius varied with the cutting speed. Also, relatively inhomogeneous chip thickness and chip curl radius distribution was observed at the lower cutting speeds. The improvement in the surface state with increasing the cutting speed can also be explained by the formation of built-up-edge (BUE) at the lower cutting speeds as the presence of BUE leads to a poorer surface finish. This is the case especially when machining very ductile materials.

CONCLUSIONS

With the machining of AISI 304 austenitic stainless steel, optimum cutting speed leading to the lowest tool flank wear has been sought and the following conclusions can be drawn from this study:

• Flank wear decreases with increase in the cutting speed. The poor performance of the tool is by the thermal softening of the tool.

• Surface roughness values also decrease with the increase in cutting speed. This can be charactererize by the presence of BUE at the lower cutting speeds. Non-uniform distribution of chip thickness at the lower cutting speeds, shows the variation in the cutting forces. Poor surface finish is due to the force fluctuations.

Experiments involving cemented carbide tool inserts and AISI 304 stainless steel work material under varying machining parameters and with three different cutting fluids were performed. Cutting fluids were considered as important parameters in the machining process along with cutting speed, feed rate and depth of cut. An analysis of variance (ANOVA) was made and it was found that feed rate has greater influence on surface roughness (61.54% contribution) and cutting speed has greater influence on tool wear (46.49% contribution). Further it was found that cutting fluid has some considerable influence on both surface roughness and tool wear. Effectiveness of the cutting fluids in reducing the tool wear and improving the surface finish was found by comparing the relative performance. In general, coconut oilwas found to be a better cutting fluid than the conventional mineral oils in reducing the toolwear and surface roughness. Surface plots were drawn between the various process parameters so as to understand more about their individual relationship and relative contribution to surface roughness and flank wear.

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