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OPTIMIZATION OF MACHINING PARAMETERS FOR THE ROUGHING OPERATION OF ASTM A744 STEEL

Otimização de Parâmetros de Usinagem para a Operação de Desbaste de um Aço ASTM A744

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Abstract

An investigation was made into the effects of the machining conditions of the turning operation on the surface integrity of ASTM A744 Grade CN3MN superaustenitic stainless steel. The main focus was the roughing operation. The input variables were cutting depth of 2.5 mm, feed rate of 0.25 mm/rot., rake angle (0 or 10°) and cutting speed (60 or 90 m/min). The tests were conducted on a CNC horizontal lathe, using a flood of cutting fluid. The following parameters were analyzed: microstructure and roughness – examined by optical microscopy; work hardening – determined by microhardness measurements; and residual stress – analyzed by X-ray diffraction. The results revealed the presence of residual tensile stress and a hardened layer on all the machined surfaces. To obtain the lowest values of roughness and residual tensile stress at a cutting depth of 2.5 mm and a feed rate of 0.25 mm/rot., the best combination was the lowest cutting speed (60 m/min) and the highest rake angle (10°).

Keywords: Superaustenitic stainless steel, machining, roughness, residual stress.

Resumo

Foram investigados os efeitos das condições de usinagem em operação de torneamento na integridade superficial do aço inoxidável superaustenítico ASTM A744 Gr.CN3MN. A operação de desbaste foi o foco principal. As variáveis de entrada foram a profundidade de corte de 2,5 mm, o avanço de 0,25 mm/rot., o ângulo de saída da ferramenta (0 ou 10°) e a velocidade de corte (60 ou 90 m/min.). Os ensaios foram realizados em um torno horizontal CNC, utilizando fluido de corte. Os parâmetros analisados foram: microestrutura e rugosidade - por microscopia ótica, encruamento - por ensaio de microdureza e tensão residual - por difração de raio-X. Os resultados mostraram a presença de tensão residual de tração e de uma camada encruada em todas as superfícies usinadas. Para obter os menores valores de rugosidade e de tensão residual de tração, para a profundidade de corte de 2,5 mm e avanço de 0,25 mm/rot., a melhor combinação das condições de corte encontrada foi a menor velocidade de corte (60 m/min) e o maior ângulo de saída (10°).

Palavras-chave: Aço inoxidável superaustenítico, usinagem, rugosidade e tensão residual.

INTRODUCTION

Superaustenitic stainless steel is composed of a predominantly austenitic structure. Its high nickel and molybdenum content and the presence of nitrogen give superaustenitic steel higher corrosion resistance than series 300 conventional austenitic stainless steel (Curtis et al., 2002). Due to their high pitting corrosion resistance, superaustenitic alloys are one of the materials used in the manufacture of components for pumps operating in maritime environments.

Machining is one of the most important processes involved in the fabrication of pump components. When an as-machined surface is in service, its quality may impair its resistance to pitting corrosion and stress corrosion (Braman et al., 2005; Rhouma et al., 2001). Surface integrity is the quality of machined surfaces interpreted as a function of the elements that describe the structure of the surface and the material. This integrity is usually defined by the material's metallurgical and chemical properties, its hardness, roughness, microstructure and residual stress (Jang et al.,1996; Matsumoto et al., 1986) (Jang et al., 1996; Matsumoto et al., 1986). The pitting corrosion resistance of a machined surface increases as the degree of surface finishing decreases (Hassiotis et al., 2006; Moyaed et al., 2003; Salina-Bravo et al., 1994; Ramanathan, 1998), while its resistance to stress corrosion increases as the residual stress introduced during machining decreases (Braman et al., 2005).

Turning is a machining process most widely used of all industrial machining processes (Shaw, 2005), representing 70% of the total number of hours spent in machining pump components. Turning is also one of the most common processes in experimental research on metal cutting (Trent et al., 2000). The turning conditions applied influence the quality of a machined surface (Diniz et al., 2003).

Not all the surfaces of cast rotary components used in pumps require good finishing and low roughness, especially when such surfaces do not require tight dimensional and geometric tolerances. Therefore, it is important to study the effects of machining on the quality of a rough-turned surface.

Since the characteristics and properties of superaustenitic stainless steel differ from those of conventional austenitic stainless steel, there is a clear need to study the machining of these steels. The objective of this work is to investigate the effect of the cutting conditions employed in the rough turning operation on the surface quality of samples of casting alloy of ASTM A743 CN3MN (1998) superaustenitic stainless steel based on an analysis of the influence of surface roughness, surface hardening and residual stress.

MATERIALS AND METHODS

The CN3MN superaustenitic stainless steel samples used in this study were cylindrical, with a 95 mm diameter and 200 mm length, cast by the static process and solution heat-treated at 1170°C for 2 hours.

Hardness was measured with a Buehler 1600-6300 microhardness tester, applying a load of 50 gf for 10 seconds. The measurements were taken from the machined surface toward the core, at intervals of 50 ìm. The hardness measured in the region of the core, which did not undergo machining, was in the order of 226 ± 7 HV.

Table 1 shows the chemical composition and PREN (*Pitting Resistance Equivalent*) values calculated by the equation: *PREN = Cr% + 3.3Mo% + 16N%*.

Table 1. ***Values of chemical compositions (% weight) and*** PRE_N.

Element	Si	C	Mo	Cr	Si	Ni	P	Mn	Cu	N	PRE_N
Sample	0.74	0.015	6.25	20.79	0.008	24.65	0.021	0.63	0.33	0.2	44.6
Standard	1 Max.	0.03 Max.	6.0 a 7.0	20 22	0.01 Max.	23.5 a 25.5	0.04 Max.	2 Max.	0.75 Max.	0.18 a 0.26	≥40

The cast samples were subjected to the finish turning operation on a CNC horizontal lathe, using abundant amounts of cutting fluid emulsion containing 6% of water. The machining parameters employed here are listed in Table 2. The experiments were performed by varying the two machining parameters at two levels, in the following sequence: orthogonal rake angle of the insert (γ_o) and cutting speed (v_c), while the parameters depth of cut (a_p) and feed rate (f) were fixed. Interchangeable hard metal inserts were used with a coating composed of Ti(C,N) + Al_2O_3 + TiN, in the ISO CNMG 120412 geometry, i.e., tool tip radius r_ε=1.2 mm, held in an ISO PCLNR 2525 M1 tool holder, with an angle tolerance (α) of 6° and a position angle (χr) of 95°.

Surface roughness was measured with a Perthometer M1–Mahr roughness tester, while residual stresses were measured with a RIGAKU D-MAX RINT 2200 X-ray diffractometer. All the hardness measurements were taken with a Buehler 1600-6300 microhardness tester, applying a load of 50 gf for 10 seconds.

RESULTS AND DISCUSSIONS

Table 2 lists the turning conditions applied and the respective values of roughness, Ra, residual tensile stress and surface hardening determined from the measurements of the machined surface.

ROUGHNESS

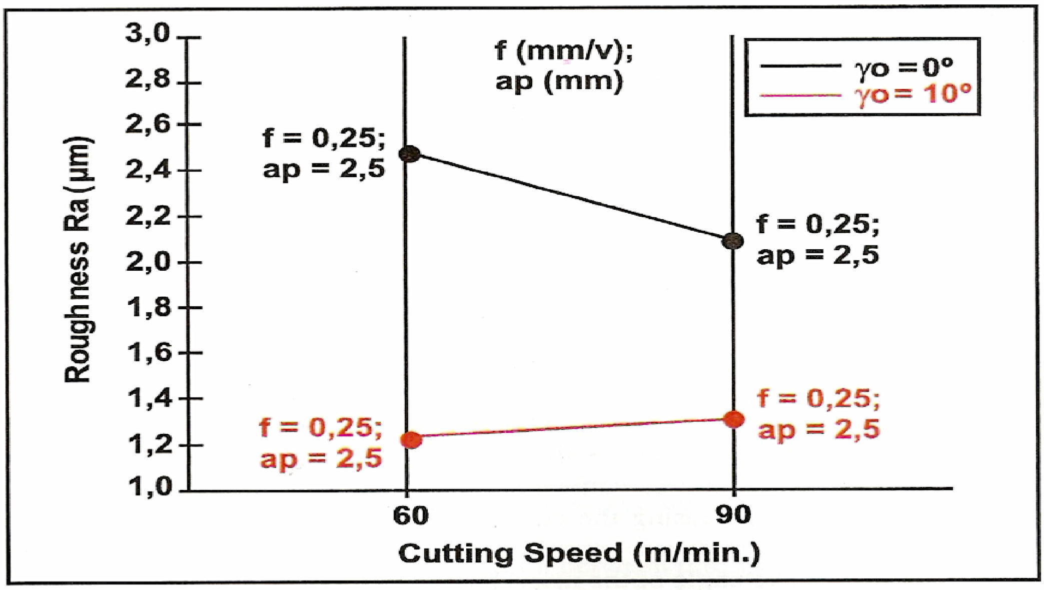
As can be seen from the results in Table 1, the variable cutting speed had a significant effect on the roughness, Ra. The graph in Figure 1 illustrates the effects of the cutting parameters applied in turning on the roughness, Ra.

In Figure 1, note that the cutting speed does not influence roughness to any appreciable extent, but roughness decreases significantly when the rake angle of the insert (γ_o) passes from 0° to 10°. This strong influence of the γ_o on roughness, Ra, indicates the high ductility of this machined material. With an increasing γ_o, the chip deformation rate decreases due to the decline in the decreasing specific cutting force (K_s).

Table 2. ***Influence of turning conditions on the surface properties of CN3MN stainless steel.***

Turning conditions				Roughness	Residual	Work hardening	
V_c (m/min)	f (mm/v)	a_p (mm)	γ_o (°)	Ra (µm)	stress (MPa)	Surface hardness (HV_{50gf})	Thickness of layer (µm)
60	0.25	2.5	10	1.22	128 ± 15	464	165
90	0.25	2.5	10	1.31	179 ± 16	440	215
60	0.25	2.5	0	2.28	223 ± 30	471	215
90	0.25	2.5	0	2.10	339 ± 41	445	265

Figure 1. ***Effect of cutting speed and rake angles on roughness Ra, for $a_p = 2.5$ mm and $f = 0.25$ mm/rot.***

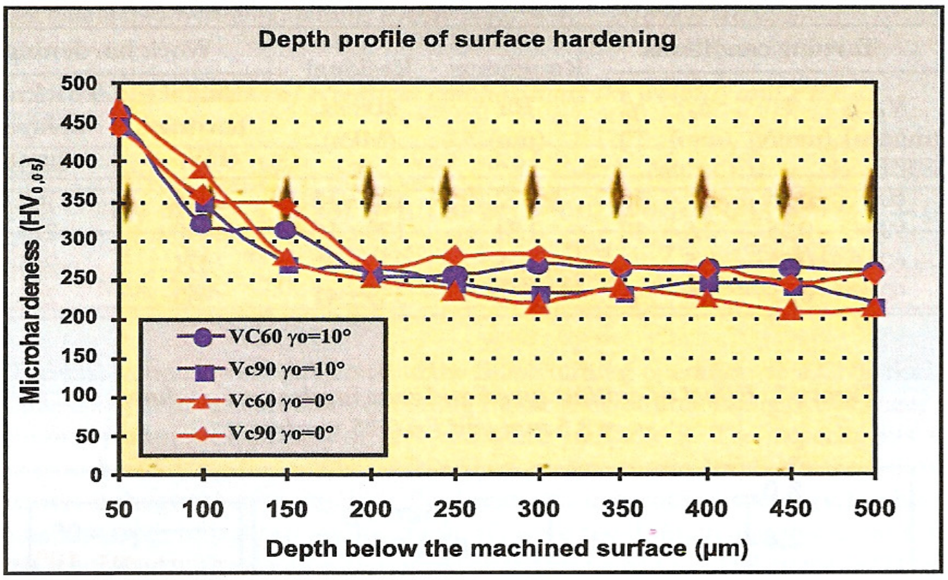


SURFACE HARDENING

The graph in Figure 2 shows the microhardness profiles of the rough-machine samples, as well as an image representing the flat surface on which the microhardness measurements were taken.

Figure 2 shows the spacing of the notched markings that were produced by the Knoop hardness tester. The measurements were taken on the surface in the direction of

Figure 2. ***Microhardness profiles of the 4 samples from the roughing operation.***



the core up to a region where the hardness value approaches that of the core. As can be seen, the rough machining did not affect the material after passing a depth of 200 μm from the machined surface. This high surface hardness can be attributed to the phenomenon of surface hardening.

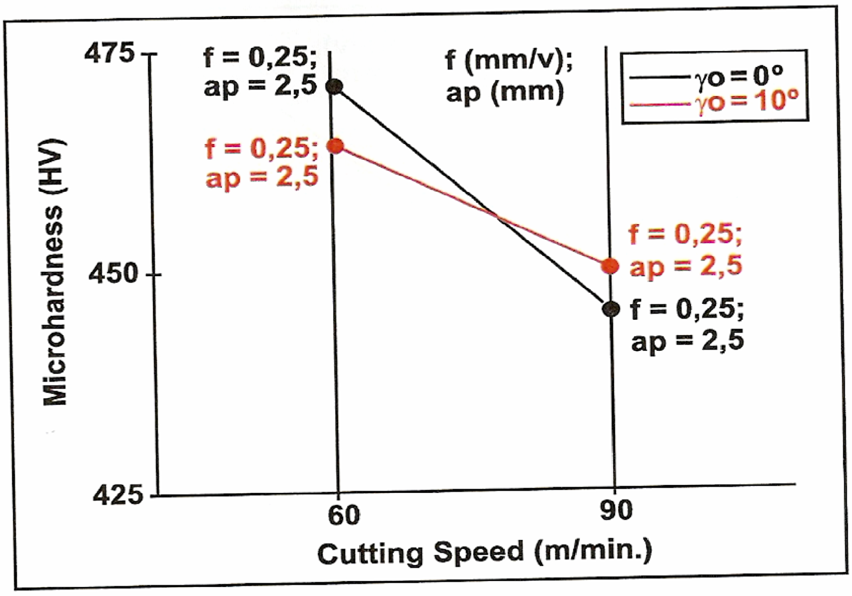
The results of Table 2 indicate that all the turning conditions applied led to a high surface hardness when compared to the core hardness. The mean surface hardness was 455 ± 15 HV. The thickness of the hardened layer varied from 165 to 265 μm, with lower values of thickness obtained with the rake angle of 10° and cutting speed of 60 m/min. The graph in Figure 3 shows the effect of the variables used in the roughing operation on the microhardness value obtained in the samples.

It was found that increasing the cutting speed from 60 to 90 m/min contributed slightly to the surface hardness, causing a reduction in the order of 25 points on the Vickers scale. The rake angle of the insert had practically no effect on microhardness.

RESIDUAL STRESS

Table 2 lists the residual stresses of the samples subjected to the roughing operation, which are positive (+), indicating residual tensile stress. The increase in residual tensile stress reduces the fatigue strength Cullity et al., 2001). Tensile corrosion resistance is correlated with residual stress. The lower the values of residual tensile strength the lower is the possibility of cracking (Braham et al., 2005). The graph in Figure 4 illustrates

Figure 3. *Effect of cutting speed and rake angles on surface hardness at $a_p = 2,5$ mm and $f = 0,25$ mm/rot.*



the effect of the variables used in the roughing operation on the residual stress obtained in the samples.

Figure 4 indicates that increasing the tool rake angle to 10° and decreasing the cutting speed to 60 m/min the residual stress is reduced.

CORRELATION BETWEEN THE INPUT VARIABLES AND THE RESULTS OBTAINED

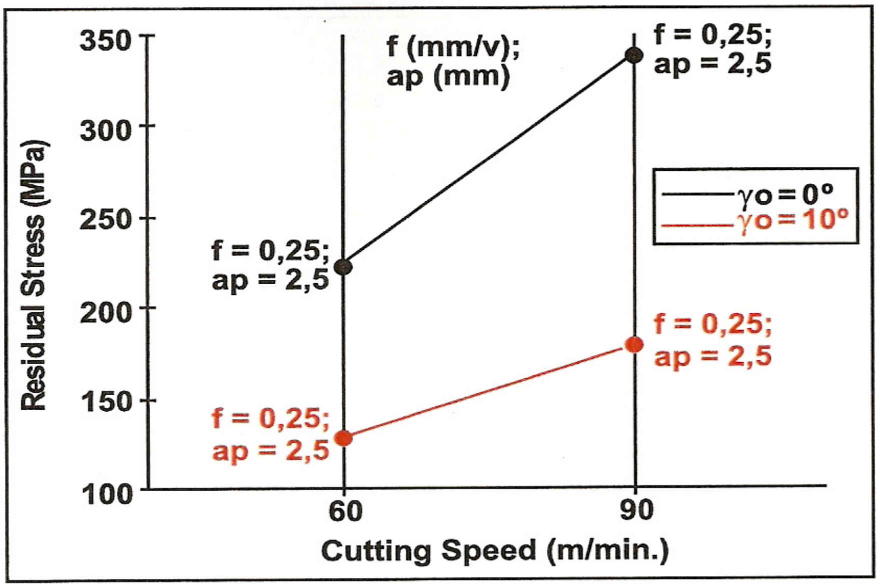
Table 3 classifies the effect of the variables applied during machining on each of the three parameters of surface quality analyzed, according to the criterion of importance described below.

1 Low roughness Ra. There is a correlation between pitting density per unit area and roughness, Ra. The lower the Ra the higher is the pitting corrosion resistance (Salina-Bravo et al., 1994; Ramanathan, 1998; Tuthil ET al., 1992).

2 Low residual stress. With regard to residual tensile stress, the lower the value the higher the fatigue strength and the tensile corrosion resistance, even if the value does not reach the tensile yield point of the material (Cullity et al., 2001). In the study of tensile corrosion resistance of 316L austenitic stainless steel, no cracks appeared at the lowest values of residual tensile stress (Braham et al., 2005).

3 Low microhardness. It was found that all the variables applied during machining led to surface hardening. The hardness, which ranged from 357 to 445 HV, indicates that

Figure 4. ***Effect of cutting speed and rake angles on residual stress at $a_p = 2.5$ mm and $f = 0.25$ mm/rot.***



all the samples underwent severe surface hardening when compared to the hardness of 211 HV of the core. Hardening is a characteristic that reduces the tool's life during machining, impairing machinability. The techniques for minimizing hardening include reducing chip deformation (higher V_C, f and $ã_o$) (Shaw, 2005; Trent et al., 2000; Diniz et al., 2003).

From Table 3 it can be seen that to reduce the residual stress and roughness after rough machining requires increasing the tool's rake angle. To reduce surface hardness requires decreasing the cutting speed. Hence, the combination of variables recommended for rough machining is: $v_c = 60$ m/min. and $\gamma_o = 10°$.

Table 3. ***Effect of the variables on the surface quality.***

Surface integrity in the roughing operation	Roughness, Ra	Hardened surface layer	Residual stress
⇧ Cutting speed (V_c)	⇳	⇩	⇧
⇧ Rake angle – γ_o (°)	⇩⇩	⇳	⇩⇩

⇩ Lower – minor effect ⇩⇩ Lower – strong effect
⇧ Higher – minor effect ⇧⇧ Higher – strong effect ⇳ Neutral effect

CONCLUSIONS

For the ASTM A744 Gr. CN3MN superaustenitic stainless steel subjected to rough turning machining applying the parameters of: feed-forward (f) of 0.25 mm/rot., cutting depth (a_p) of 2.5 mm, cutting speed (v_c) of 60 and 90 m/min, and rake angle of the insert (γ_o) of 0 and 10°, it was concluded that:

- Increasing the tool's rake angle from 0° to 10° resulted in a marked decrease in roughness, Ra, and residual stress, but had no effect on surface hardness.
- Increasing the cutting speed from 60 to 90 m/min led to a minor reduction in surface hardness and a slight increase in residual stress. The variation in cutting speed did not affect roughness, Ra.
- Among the variables applied in this study, the combination recommended to improve the surface integrity is the lowest cutting speed (v_c = 60 m/min.) and the highest rake angle (γ_o = 10°).

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