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Effect of machining configuration on the corrosion of mild steel

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ABSTRACT

The effect of machining parameters (rake angle and turning speed) at fixed feed rate and depth of cut on corrosion behavior of mild steel is addressed in the present study along with analysis of tribological properties of the machined samples. Immersion and salt-fog exposure tests in 3.5% NaCl are carried out to understand the corrosion behavior of the machined samples. Detailed microstructural characterization of the machined samples (optical metallography and scanning electron microscopy) and their rust constituents as determined by Fourier transform infrared spectroscopy is used to establish microstructure-properties correlation.

1. Introduction

Mild steel is one of the most versatile and resilient materials, and it forms the backbone of wide varieties of heavy machines as well as for various industries due to low cost and good mechanical strength. Various grades of mild steels have found widespread usage in making ships, submarines, dry docks, floating docks, slip ways and offshore structures, where highly corrosive marine environment is experienced. Components made out of steel have to undergo wide varieties of manufacturing operations including machining before they are utilized in structural as well as non-structural applications.

Machining operations involve removal of metal from a workpiece with the help of a tool made of material harder than the workpiece. Turning operation is one of the simplest and most widely used machining processes. Nian et al. (1999) reported in their paper that proper selection of cutting parameters in turning operation is of high importance for generation of good surface finish. Hussain et al. (2009) studied the pronounced effect of the quality of surface generated after the machining process on fatigue resistance. However, they found an increase in fatigue resistance of the samples with smooth surfaces as compared to the samples with scratches. Ghosh and Kain (2010) reported increased susceptibility to stress corrosion cracking of the machined samples as compared to that of the solution annealed stainless steel samples. Dubovska et al. (2014) presented a list of qualitative indicators to assess the integrity of the machined samples with most common surface finish, influencing some of the functional properties, such as fatigue strength, wear and corrosion stability. Cai et al. (2009) reported that machining led to severe plastic deformation. Lee et al. (2006) demonstrated that machining involved large strain, high strain rates and high temperature in the deformation zone. Swarninathan et al. (2005) suggested the interactive effects of strains, temperature and material transformations on microstructure. Shekhar et al. (2012) studied machining induced severe plastic deformation (SPD) on the chip and the machined surface to cause microstructural transformations, which could often result in fine grained surface morphology.

These machined components are at many instances exposed to moderate to severely harsh conditions, like humid and hot environment to other corrosive agents, like sea water, industrial wastes, moisture, etc. Yamashita et al. (1994) reported that rust of the weathering steel consisted of two layers, where the outer rust layer comprised of γ-FeOOH, and the inner layer composed of densely packed nano-particles of α-FeOOH. Misawa et al. (1974a, 1974b) studied that γ-FeOOH component had about 10^4–10^5 times larger solubility in comparison with α-FeOOH. Fuente et al. (2011) evaluated corrosion products of mild steel obtained after long-term atmospheric corrosion. The corrosion product consisted of γ-FeOOH, α-FeOOH and Fe_3O_4/γ-Fe_2O_3. Similarly, Oha et al. (1999) reported protective layer (α-FeOOH and superparamagnetic γ-Fe_2O_3) on the weathering steels. In view of large amount of information available on the atmospheric corrosion of steel, scant attention has been paid to corrosion behavior of mild steel as a

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function of machining parameters, like rake angle, speed, etc. Since machining is inevitable in many instances of marine applications, it demands detailed analysis of the corrosion behavior of mild steel as a function of machining parameters.

Ghosh and Kain (2010) reported machining of the AISI 304L stainless steel, where transformation of austenite matrix to strain induced martensite due to high amount of work hardening was mentioned. The study also revealed that susceptibility of stress corrosion had a close relationship with the surface machining condition. Gravier et al. (2012) postulated that surface characteristics affected the corrosion behavior to a great extent. The corrosion behavior largely depended on the machined surface conditions in copper based alloys.

Hence, the present study aims to understand the effects of machining process on the corrosion behavior of a mild steel. The work is intended to bring out the effect of variation of the machining parameters on the surface microstructure of the machined surface, and subsequently, on the corrosion behavior. The effect of interplay of deformation parameters, strain, strain rate and temperature rise on the corrosion behavior is also going to be evaluated with the help of immersion and salt fog tests using 3.5% NaCl solution. The machined surfaces have been prepared by turning operation in a lathe at different rake angles (+20, 0 and −20° angles) and varying speeds (low = 41 mm/s, medium = 276 mm/s, and high = 541 mm/s) keeping feed rate and depth of cut constant. Tribological properties of the machined and polished samples as well as chips obtained during machining have been measured to understand the effect of machining on surface roughness, strain imposed on chip, strain rate, tool tip temperature, and its subsequent correlation with corrosion properties.

2. Experimental procedure

In the present study, a commercially available cylindrical mild steel rod with diameter of 16 mm was used for preparation of samples for machining. The samples were annealed at 600 °C for 1 h to ensure fully coarsened starting microstructure. The composition of the sample was analyzed by BAIRD SPECTRO VAC DV-6 optical emission spectrometer (Table 1).

2.1. Machining

Turning operation was carried out using a lathe. Nine samples of length 25 mm were prepared by varying the rake angle and turning speed, keeping the depth of cut and feed rate constant. The details of the machining parameters are depicted in Table 2. For all the turning operations, sharp high-speed steel tool ground into suitable geometries was used. The tool geometry and its interaction with the machined surface are shown in Fig. 1. a_c is the chip thickness, and a_0 is the thickness of the interacting material before chip formation.

Table 1
Composition of steel (in wt%).

C	Si	Mn	S	P	Ni	Cr	Mo	V
0.15	0.14	0.79	0.018	0.026	<.010	0.013	0.004	0.003

Table 2
Machining parameters.

Rake angle	20°, 0°, −20°
Turning speed	41mm/s, 243mm/s, 541mm/s
Feed rate	0.177 mm
Depth of cut	1.5 mm
Tool	High speed steel

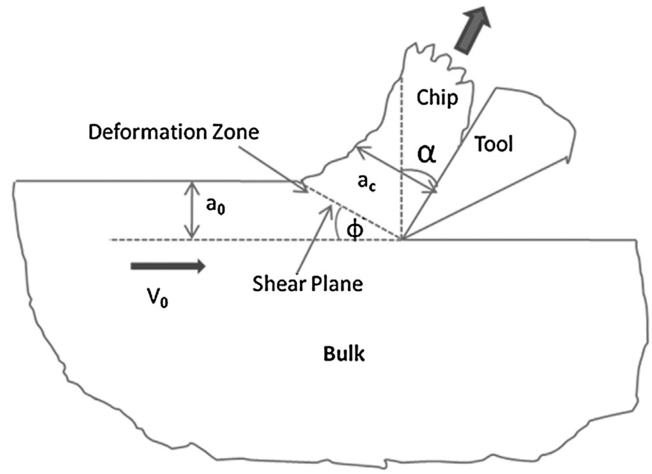

Fig. 1. Machining configuration used for creating various surface microstructures.

The rake angle is α, and it was varied from −20 to +20°. ϕ is the shear angle. V_0 is the relative velocity of the bulk and cutting tool.

All the nine samples produced were named as 20L, 20M, 20H, 0L, 0M, 0H, −20L, −20M, −20H and the as-received sample as AS. The numbers represent the rake angles 0°, 20°, and −20°, and the alphabets, L, M, and H, refer to the three different linear cutting speeds: low (L) = 41 mm/s, medium (M) = 276 mm/s, and high (H) = 541 mm/s.

2.2. Roughness measurement

The average surface roughness from five measurements for the ultrasonically cleaned curved machined surface for each sample was measured using the portable roughness tester TR100. The roughness parameter, R_a (Arithmetic average of absolute values), was measured keeping a cut off length of 0.25 mm and a tracing length of 6 mm.

2.3. Chips

The chips formed by material removal during machining were collected and cleaned with water. The samples were then ultrasonically cleaned in acetone. The chips were dried, put on epoxy mount and ground successively with 120, 240, 320, 600, 800 and 1000 grit waterproof SiC papers. Final polishing was performed on cloth using 0.5 μm alumina paste. The etching was carried out with 2% nital solution (2% HNO_3 in ethanol). The hardness of the chips was studied using Vickers hardness machine BAREISS Digi-test. A force of 0.110 kg was used for measuring the hardness values. A minimum of 10 measurements was taken to find an average value and the standard deviation. Nomenclature of the chips was taken same as that for the samples. The thickness of the chips was measured using screw gauge.

2.4. Contact length

The tool chip contact length plays an important role in the metal cutting process. The contact length was measured by using following equation as given by Astakhov and Osman (1996):

$$C = t_1 \xi^{1.5}, \quad \xi = \frac{t_1}{t_2} \tag{1}$$

where, C is the contact length between chip back face and tool rake face, ξ, is the chip compression ratio, t_1 is the preset depth of the material by moving in a direction perpendicular to its cutting edge, and t_2 is the produced chip thickness after machining.