Effect of Milling Time on Surface Morphology of AISI O1

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Abstract: AISI O1 was processed by surface milling and the influence of milling time on the surface morphology was studied by 3D profilometer and scanning electron microscopy (SEM). Results show that when AISI O1 specimens are processed with various milling time, the morphology of AISI O1 changes correspondingly. Moreover, it demonstrates that the initial increase in milling time accompanies with the increase in surface roughness until the milling time reaches 60 min at which the surface roughness is the minimum.

1. INTRODUCTION

Conventionally, the surface finishing of metal molds is always done by hand lapping after milling and/or electrical discharge machining in order to attain small surface roughness without micro cracks. However, in this process operator shortcomings cause these manual processing methods to have a number of limitations. Meanwhile, consistency and repeatability are also required. Consequently, the process is extremely time-consuming, which leads to high cost [1].

Whilst automated processes, suitable for the finishing of closed dies, they are limited in their application. For example, precision machining using a single point diamond tool is slow, requires conditions not readily available in an industrial environment and is limited to flat surfaces [2-4]. Chemical micromachining and electrochemical micromachining are limited in their application and can be difficult to control [4-6].

Laser has also been widely used as a machine tool to modify the surface of the engineering materials, such as laser surface alloying, laser cladding, surface texturing, laser physical vapor deposition, laser polishing, *etc* [2, 7-12].

Ultimately, surface modifications or surface treatments are vitally taken for increasing service life of the critical components and devices used for engineering and structural functions. Numerous surface engineering approaches just as the above mentioned such as thermal, chemical, mechanical, as well as hybrid treatments are employed to improve or vary/change the surface finish.

In this work, an attempt has been made to vary the morphology of AISI O1 by surface milling. The morphology of the initial surface was studied. After processed, the influence of milling time on the surface morphology of AISI O1 was studied by 3D profilometer and scanning electron microscope (SEM).

2. EXPERIMENTAL MATERIAL AND PROCEDURES

2.1. Experimental Material

The chemical composition of AISI O1 tool steel is shown as Table **1**.

Table 1: **Chemical Composition of AISI O1 Tool Steel**

Element	C	Si	Mn	Cr	W	V	Fe
(wt.%)	0.9	0.3	1.2	0.5	0.5	0.1	Bal.

2.2. Experimental Procedures

The materials were machined into 25 mm × 25 mm × 5 mm and carefully cleaned by acetone and pure ethyl alcohol to remove any contaminants on its surface. Figure **1** shows the Talysurf 3D topography of the original AISI O1 tool steel

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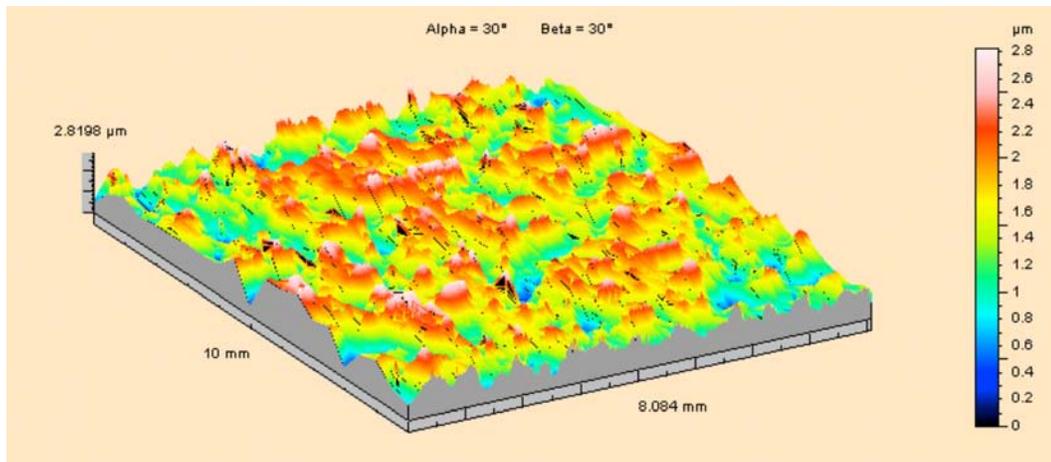
 Figure 1: Topography of the original AISI O1.

specimen, whilst Figure **2** shows its corresponding 2D SEM morphology.
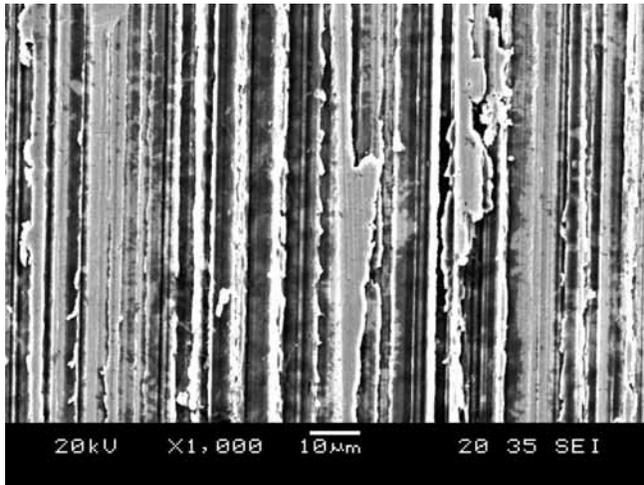
Figure 2: SEM of the initial AISI O1 surface.

The planetary mono mill "Pilverisette 6" (Made in Germany) was used for surface milling in the stainless steel milling bowl (Volume is 500 ml). The process was performed under the vacuum condition to prevent contaminations for 15 min, 30 min, 60 min, 120 min and 180 min with the milling speed setting as 250 rpm, respectively. All the processed specimens were ultrasonically cleaned in an acetone bath for 10 minutes with 28 ~ 34 Hz frequency and carefully dried. The surface morphology of surfaces was observed by Taylor Hobson profilometer/Talysurf PGI, Optical Microscope (OM), and Scanning Electron Microscope (SEM) JEOL/JSM-5600.

3. RESULTS AND DISCUSSION

3.1. Morphology of Machined Surface at Various Milling Times

The morphology of machined surface after 15 min milling is shown in Figure **3** and its related SEM image is shown in Figure **4**.

It indicates that the machined surface is smoother than its initial surface (Figures **1** and **2**). According to Figures **3** and **4a**, it demonstrates that there are some small ridges distributed on the machined surface. Compared Figures **3** and **4** with Figures **1** and **2**, the grooves on the surface disappear, together with some smaller island-form ridges (such as labels A and B) due to the shorter milling time. The big ridges cannot be detected and the remained chippings disappear (Figure **2**), resulted in the smooth machined surface shown as Figure **4a**.

Moreover, the magnified parts of Figure **4a** are shown in Figures **4b** and **4c**, crack can be found on the machined surface as shown in Figure **4c** (label C) as a result of effect of milling balls.

The morphology of machined surface after 30 min milling time is shown in Figure **5**, and its corresponding texture is shown in Figure **6a** and its magnification parts Figures **6b** and **6c**. Although milling balls remove most high plateaus from the original surface of the specimens (cf. Figures **2** and **6**), the island-form ridges still distribute on the machined surface. As expressed in Figures **6b** and **6c**, micropits and cracks can be observed on the surface of the substrate because the balls do not mill sufficiently.

With the increase of milling time, the machined surface becomes more and more smooth as shown in Figure **7**, and the formed ridges become smaller and distribute uniformly as shown in Figure **8** where the magnifications of Figure **8a** are shown in Figures **8b** and **8c**. It illustrates the uniform changes of the surface topography after 60 min milling time. The variation of the topography of the surface machined at 60 min is distinct. It is observed that the AISI O1surface was machined effectively without any defects (cf. Figures **4**, **6** and **8**).

Generally, increase in milling time simultaneously improves the properties of the surface substrate. However, too longer milling time will be likely to destroy the surface of substrate which subsequently changes the surface topography and mechanical properties of the steel specimens.
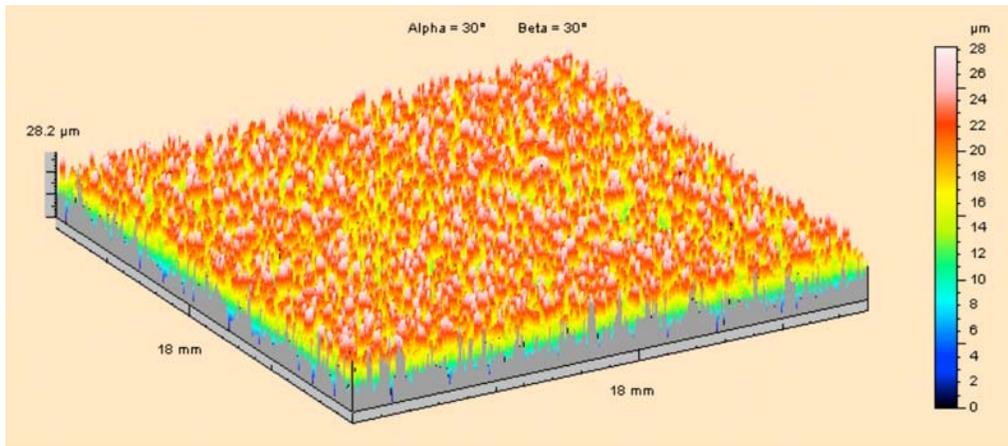
Figure 3: Morphology of machined surface after 15 min milling time.
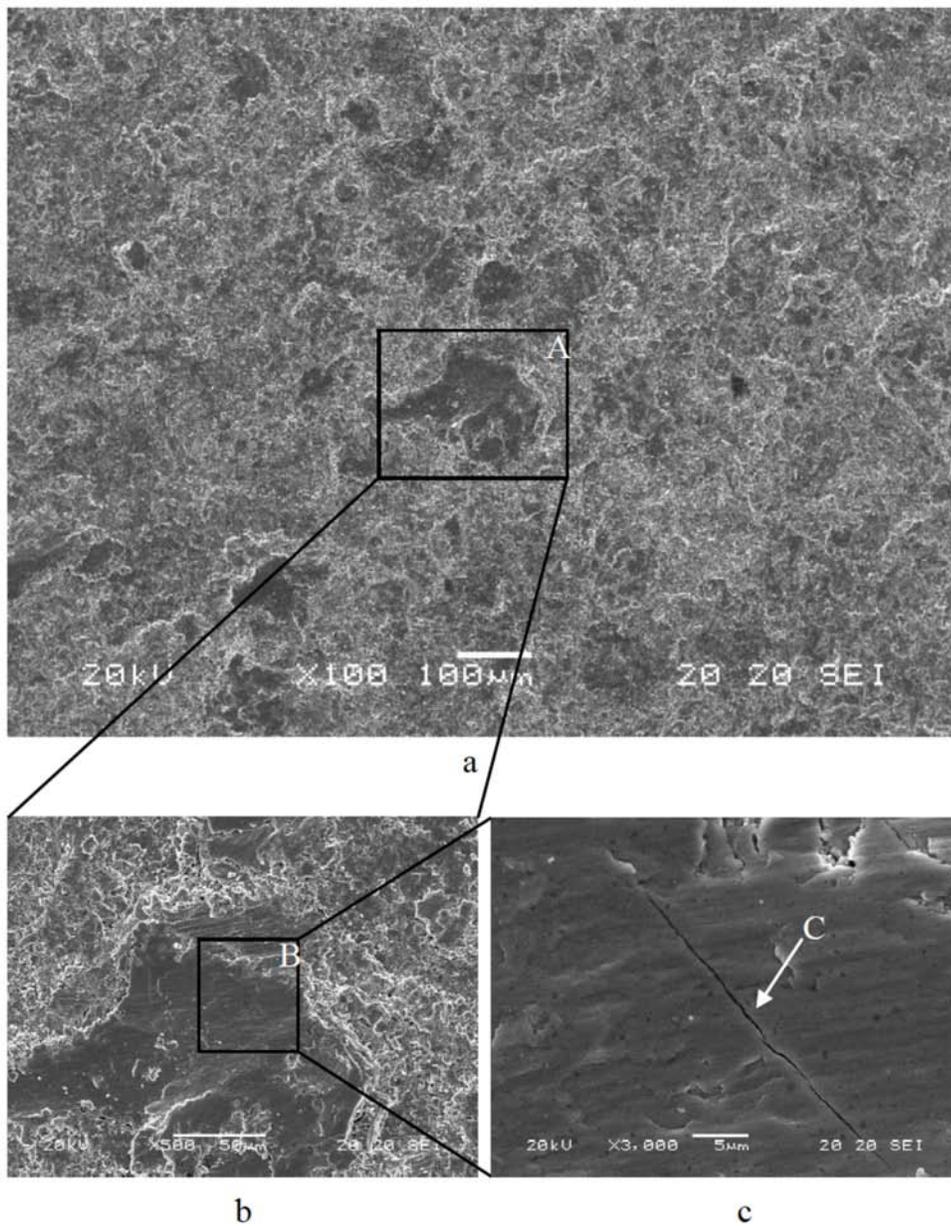
Figure 4: Machined surface after 15 min milling time.
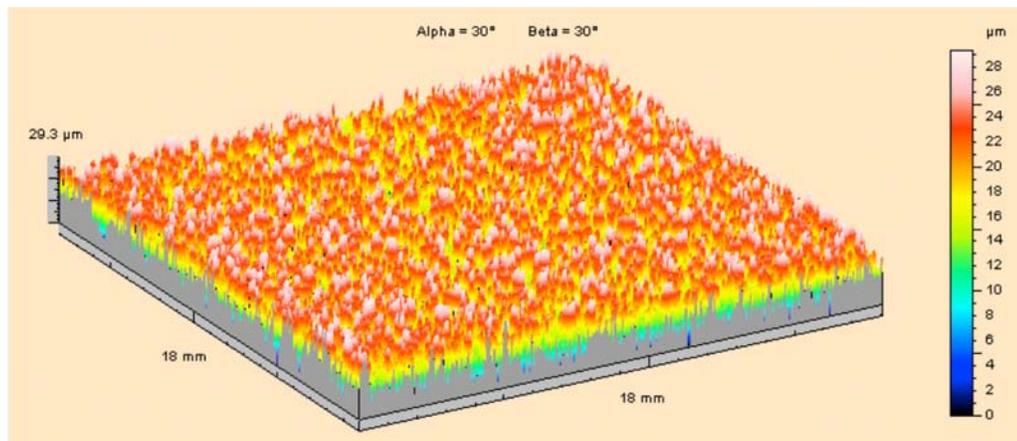
Figure 5: Morphology of machined surface after 30 min milling time.
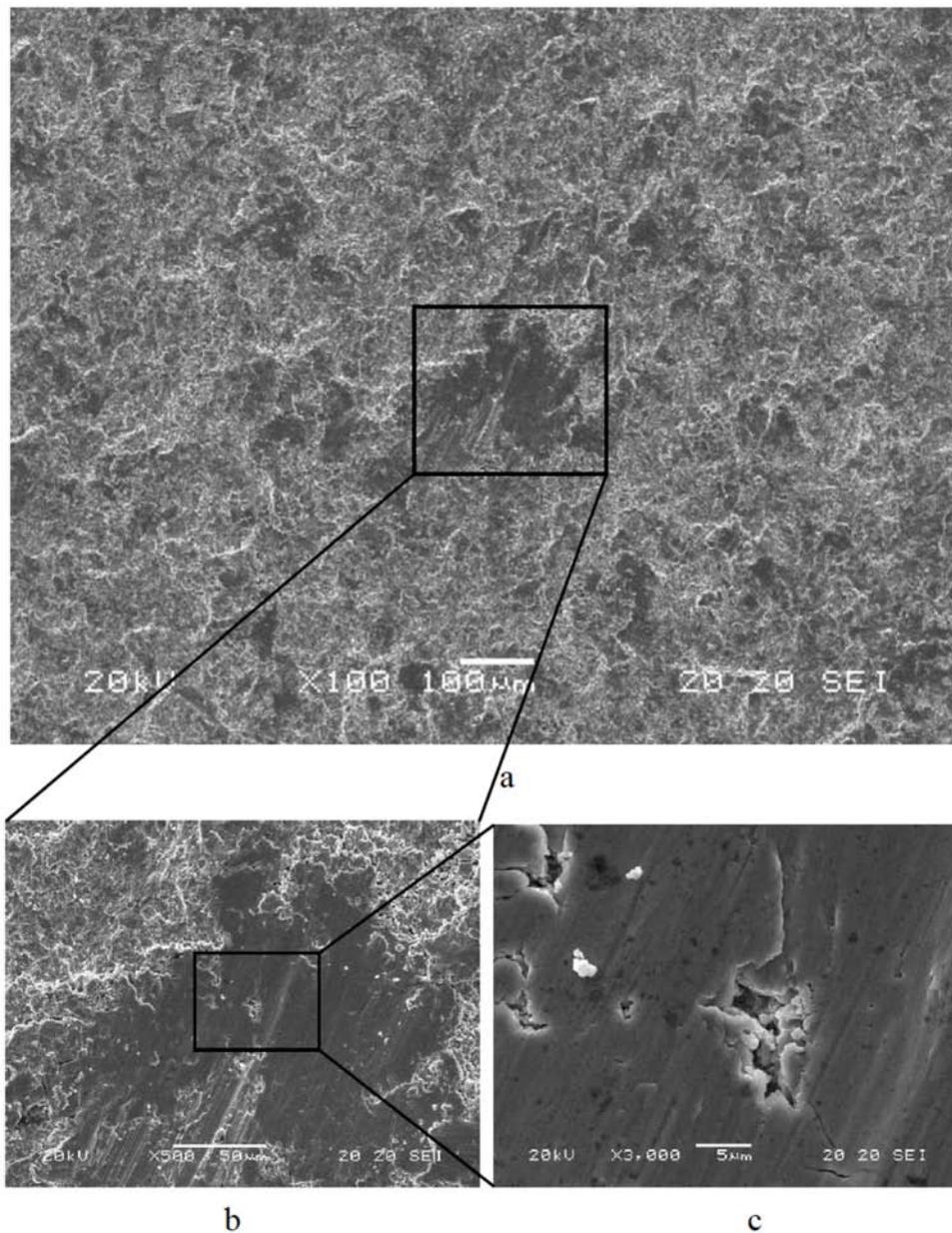
Figure 6: Machined surface after 30 min milling time.
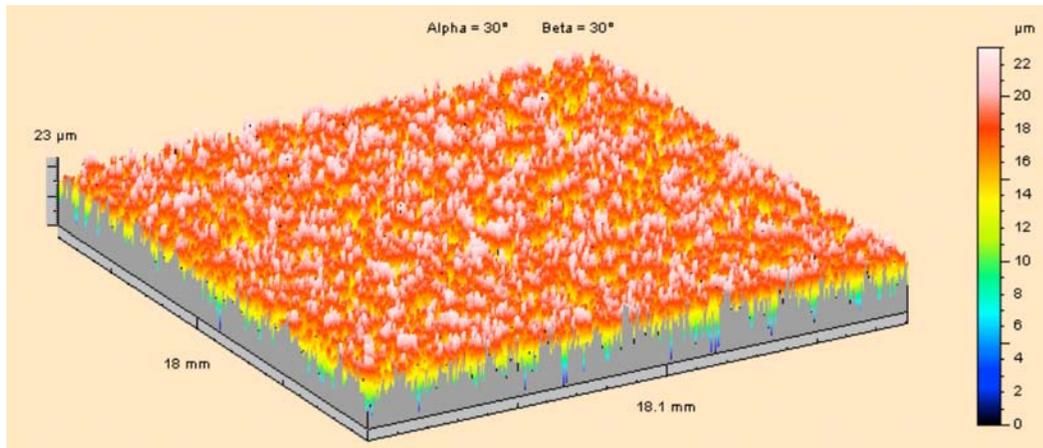
Figure 7: Morphology of machined surface after 60 min milling time.
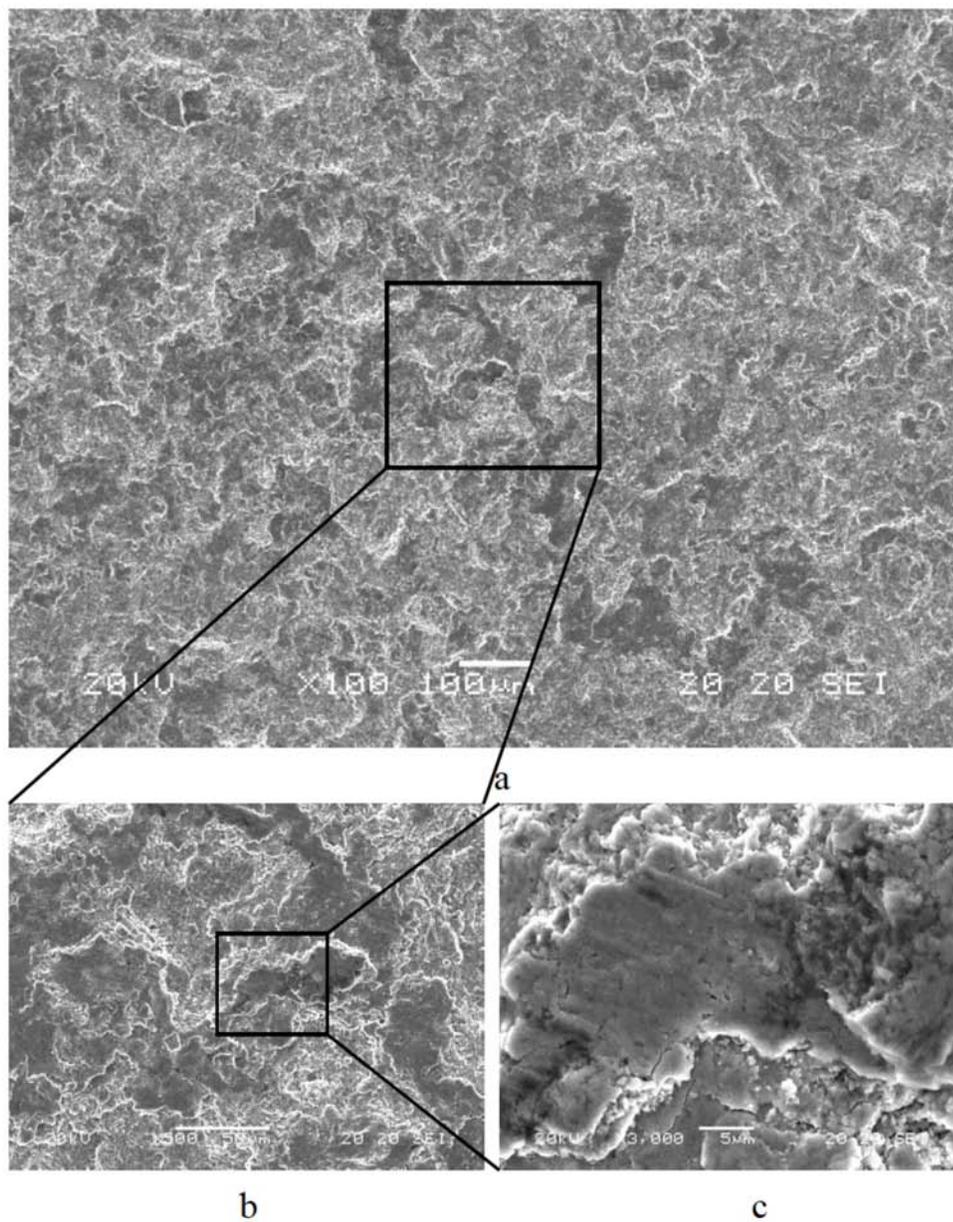
Figure 8: Machined surface after 60 min milling time.
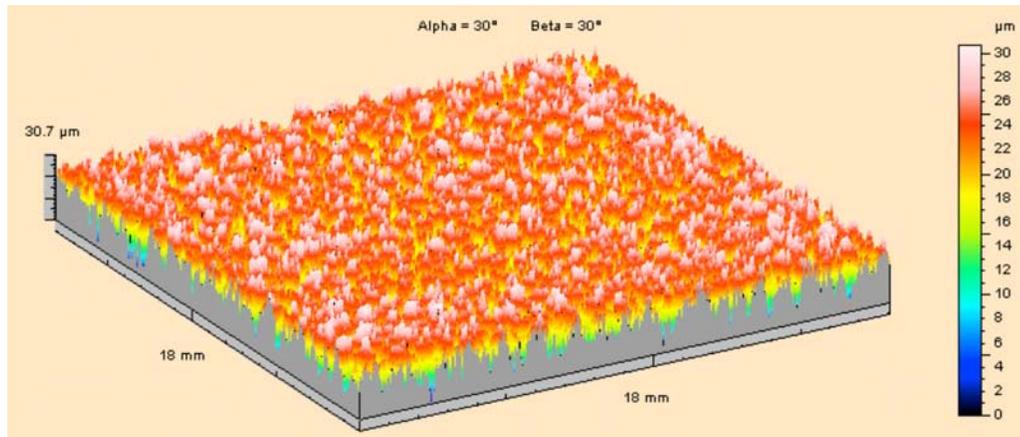
Figure 9: Morphology of machined surface after 120 min milling time.
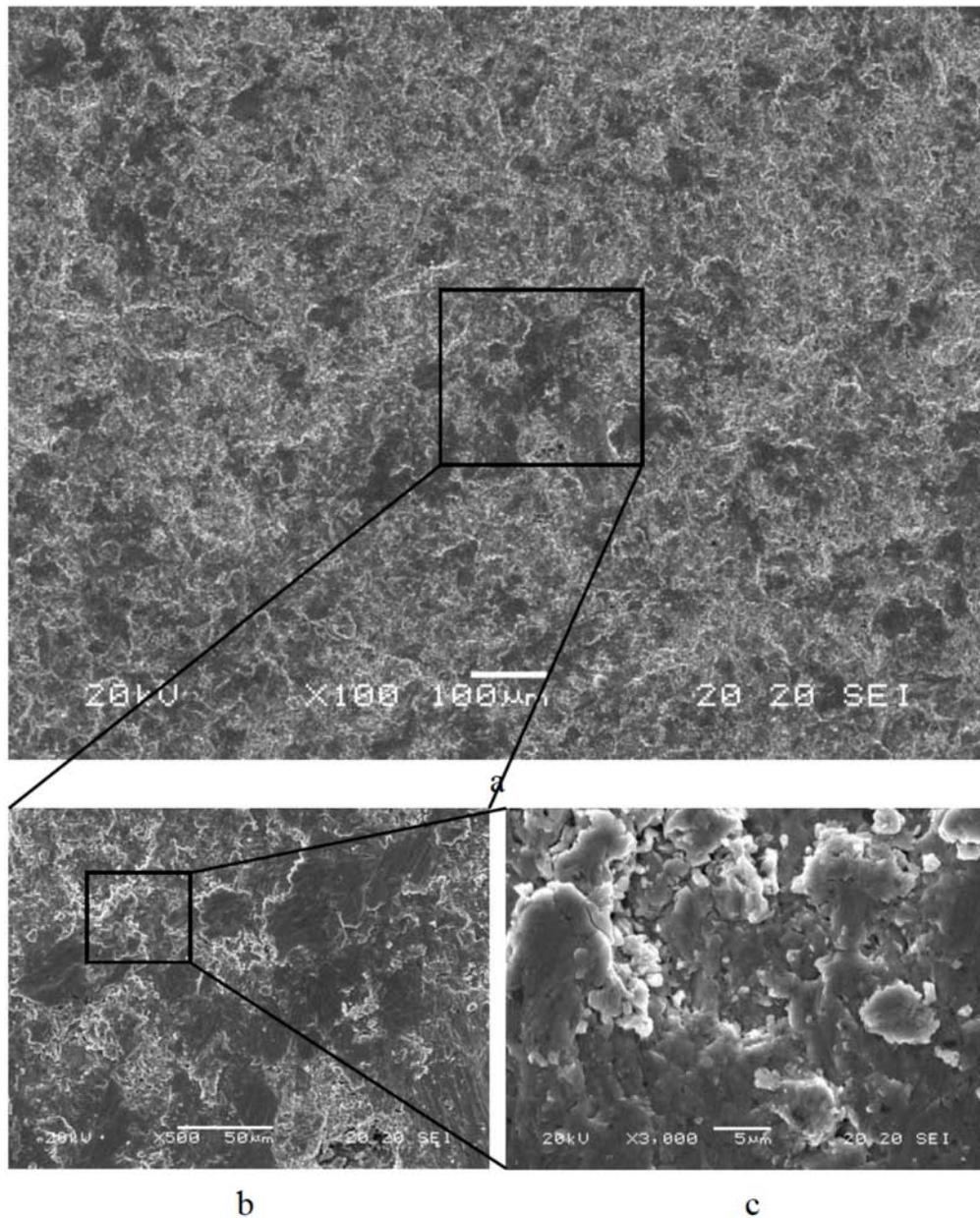
Figure 10: Machined surface after 120 min milling time.
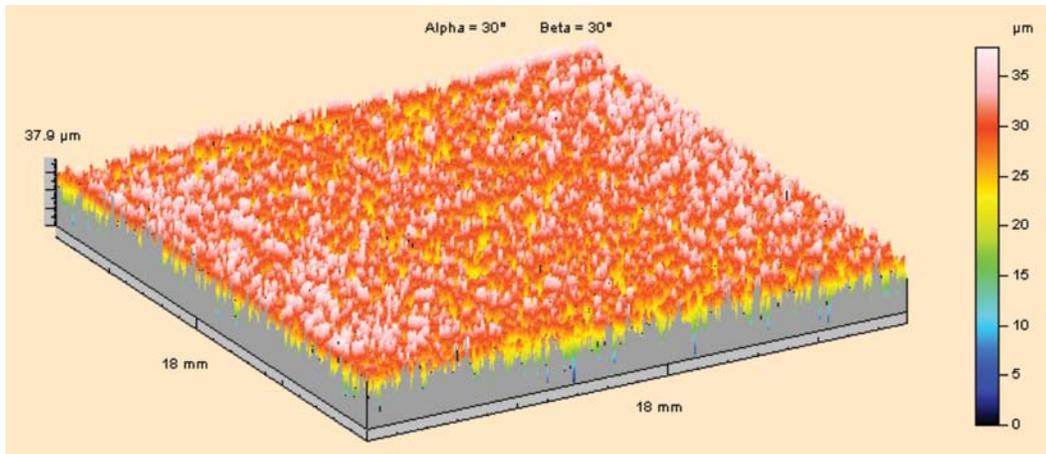
Figure 11: Morphology of machined surface after 180 min milling time.
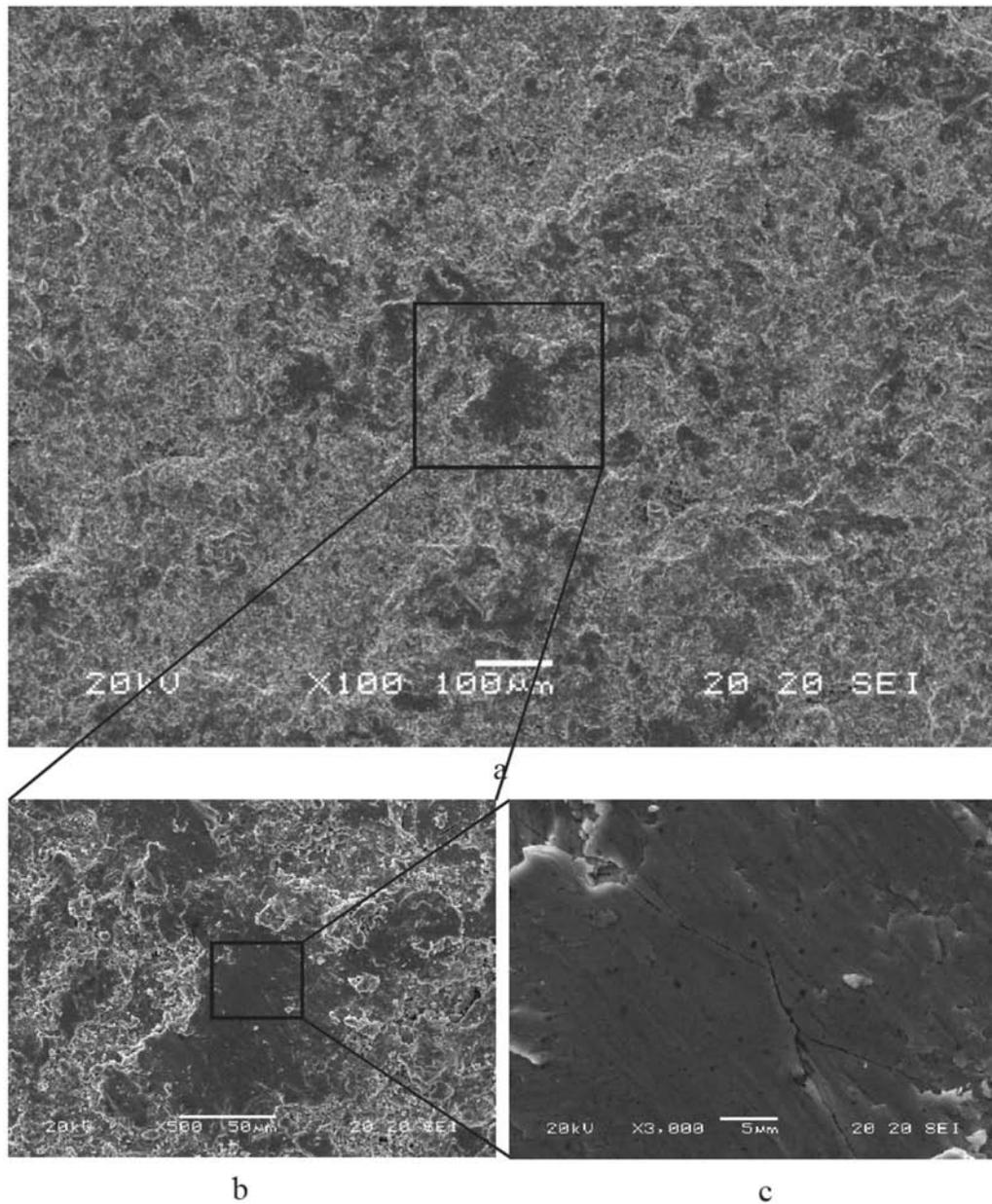
Figure 12: Machined surface after 180 min milling time.

When compared with the machined surface of 60 min milling time (Figure **8**), the machined surfaces (Figures **9** and **11**) of longer milling time give relatively coarser surface. Also, its SEM image (Figures **10a** and **12a**) and the further magnified counterparts (Figures **10b**, **10c**, **12b** and **12c**) show the sign of ridges re-growing bigger, some microparticles aggregating loosely and microcracks scattering on the machined surface. Such surface topography with scattering of micro-aggregation and micro ball-like amorphous features (Figure **10c**) implies that there is some level of change of properties of AISI O1 surface. This change is not really anticipated since it is initially expected that the properties of the machined surface topography would be the same as its as-received condition or higher than the initial one.

At longer milling time (i.e. 180 min), besides the morphology of the machined surface changes obviously (Figure **11**), relatively more severe cracks appear as shown in Figures **12b** and **12c**, which are likely to change the properties of the initial surface drastically.

3.2. Roughness of Machined Surface

Figure **13** shows the relationship between the arithmetic mean surface roughness Ra and the milling time. Results indicate that the initial increase in milling time accompanies with the increase in surface roughness until the milling time reaches 60 min at which the surface roughness is the minimum. Then, further increase in the milling time increases the roughness once again which agrees well with morphology shown in Figures **3** ~ **12**.
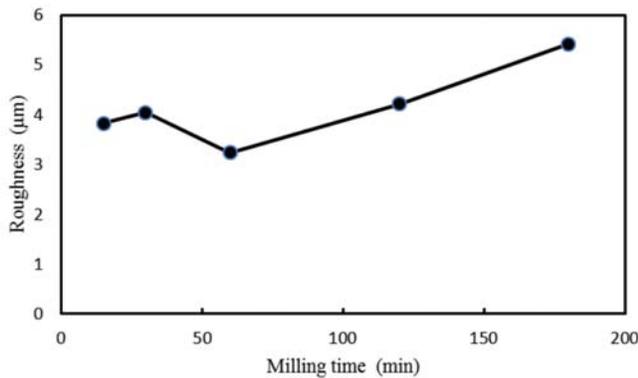
Figure 13: Relationship between Ra and milling time.

3.3. Preliminary Calculation Model

During the milling process, the mean value of the magnitude of the critical torque $\overline{\tau_{crutical}}$ can be expressed as:

$$\overline{\tau_{crutical}} = \lambda_\tau d_t [F_n + 3 f_{adhesion}]$$ (1)

where λ_t is a constant in the range $0.5 < \lambda_t < 1$, d_t is the distance parallel to the plane from the center to one of the asperities in contact, $f_{adhesion}$ is an adhesive force at each contact, F_n is the normal body forces.

$$\overline{\phi_{critical}} = \lambda_\phi \frac{2 \left(\frac{3 |P + f_{adhesion}|}{4 E^* \sqrt{R^*}} \right)^{\frac{2}{3}}}{3 d_t}$$ (2)

$\overline{\phi_{critical}}$, the critical angle at which critical torque $\overline{\tau_{crutical}}$ occurs, $0.63 < \lambda_\emptyset < 1$, P is the total load, the reduced radius,

$R^* = \dfrac{R_1 R_2}{R_1 + R_2}$, and reduced elastic modulus,

$E^* = \dfrac{E_1 E_2}{E_1(1 - \upsilon_2^2) + E_2(1 - \upsilon_1^2)}$.

$$\overline{\tau_{decelerating}} = -\gamma \omega$$ (3)

where $\gamma = -2 \xi \eta_n |d_t|^2 n_{2\pi}$

$\overline{\tau_{decelerating}}$ is the decelerating torque, ξ is the coefficient ($\xi < 1, or\ \xi \ll 1$), η_n is the damping coefficient, ω is the angular velocity, $n_{2\pi}$ is the number of asperities per revolution. γ is the adhesive force.

The model consists of expressions for the critical angle and torque at which a ball starts to mill, as well as the rate at which they decelerate. Because of the stochastic nature of surface roughness, it is impossible to accurately reproduce all behavior in a model simple enough to be used in the ball milling phenomena reconstructions. While average milling effect can be accurately replicated, the contact between a real ball and the substrate will not necessarily follow this average due to the details of the geometry. However, in a system of many balls it is often the case that the average behavior dominates. While variations around the average may have a large effect on the motion of each individual ball, the statistical behavior of a system of many balls will not be significantly changed. The model has been derived for contact between a ball and a plane. The contact forces in contacts between two balls will be different, and effects such as interactions between asperities make the system far more complex, but the general principle upon which the model is based still applies. The proposed model can provide an adequate approximation of milling effects in the surface processing when torque is dominated by the largest scale of roughness.

CONCLUSIONS

The morphology of AISI O1 varies with the different milling time. Increase in milling time simultaneously improves the surface morphology of the substrate. However, too longer milling time will be likely to destroy the surface of substrate which subsequently changes the surface topography and mechanical properties of the steel specimens, which is not really anticipated since it is initially expected that the properties of the machined surface topography would be the same as its as-received condition or higher than the initial

one. Also, the initial increase in milling time accompanies with the increase in surface roughness until the milling time reaches 60 min at which the surface roughness is the minimum.

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