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Expression for Surface Roughness Distribution of FDM Processed Parts

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Abstract: Rapid Prototyping (RP) processed parts are mainly fabricated by layered manufacturing process. Hence stair steps occur at surface of the part and affect the quality of the surface. Also, the surface roughness by the stair step depends on surface angle. Therefore, prediction of the surface roughness distribution by the change of surface angle for a part to be processed is required on the process planning stage of the RP. This paper proposes a methodology to express surface roughness distribution of the part which is processed by the FDM. In order to reflect actual roughness distribution in computing, a surface roughness distribution equation is presented based on interpolation using measured roughness values. And, the computing accuracy by the number of the measured roughness data is analyzed. The implemented results show that the proposed methodology can be practical.

Keywords: Rapid Prototyping, FDM(Fused Deposition Modeling), Surface Roughness

1. INTRODUCTION

Rapid Prototydping(RP) is an additive manufacturing technology that can fabricate 3D physical models without geometric restrictions by stacking and bonding 2D layers in a given direction. Hence, the application technologies such as SL, SLS, FDM, ROM have developed and expanded to industrial fileds [1, 2]. However, because most RP technologies use layered manufacturing process, stair steps occur at inclined surface of the RP processed parts [3-5]. The stair step form varies according to RP technology. But the stair step absolutely affects the surface quality of the RP processed parts [4, 5]. Therefore, the prediction for the surface roughness distribution is important in the process planning stage of the RP.

A methodology to express the surface roughness distribution of the FDM (Fused Deposition Modeling) processed parts is presented in this paper. In order to reflect actual roughness distribution in computing, a surface roughness distribution equation is presented based on interpolation using measured roughness values. And, the computing accuracy by the number of the measured roughness data is analyzed. The implemented results show that the proposed methodology can be practical.

2. SURFACE ROUGHNESS DISTRIBUTION

LM process is usually performed by stacking layers which have some level of thickness, the stair stepping effect occurs on surface of the LM part as shown in Fig. 1. Due the effect, geometrical gap occurs between the original CAD model and the fabricated LM part. Also, the figure shows that this error varies according to the surface angle. From the approximated modeling for the stair stepping effect, a theoretical distribution model for average surface roughness (Ra) according to changes in the surface angle can be expressed by equation (1). In equation (1), L denotes the layer thickness, θ is the surface angle, θ is the surface profile angle, A and W denote the step area and step width, respectively [5].

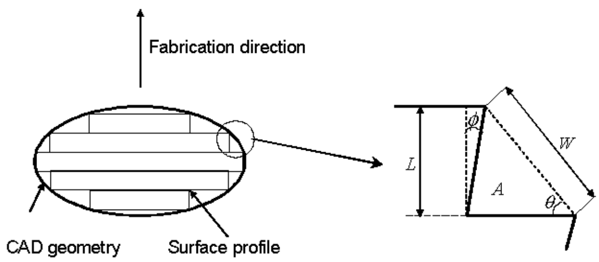


Fig. 1 Stair stepping effect of the LM processed parts

$$R_a = \frac{A}{w} = \frac{L}{2}\left|\frac{\cos(\theta - \phi)}{\cos\phi}\right| \quad (0° < \theta < 180°) \quad (1)$$

Through equation (1), the relationship between the main LM process factors and the average surface roughness by changes in the surface angle is graphed in Fig. 2. Where, the applied layer thickness is 0.025-0.1*mm*, the profiles angles are 5-15°. These values are used in the general LM technologies. The surface angle range is formed both right and left on the basis of fabrication direction with angle 0-180°. Fig. 2 shows a surface roughness distribution by the change of surface angle. This is typically theoretical distribution of the RP processed part, where, the layer thickness is *0.1mm* and profile angle is *5°* [6]. However, the actual distribution of the surface roughness is different from that of the theoretical surface roughness. This is due to various factors which are stair stepping effect, support removal burrs, material properties and process attributes, as described in Eq. (2) [3, 4].

$$R_{actual} = R_{step} + R_{burr} + R_{material} + R_{process} \quad (2)$$

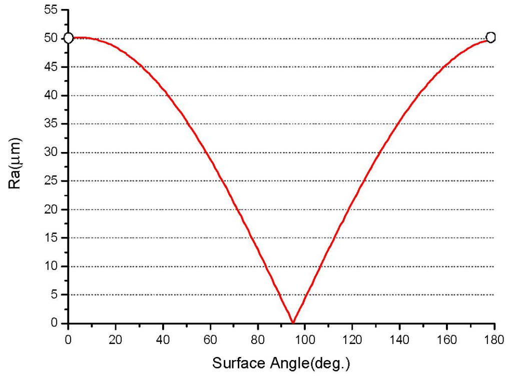
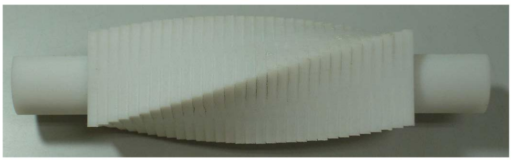
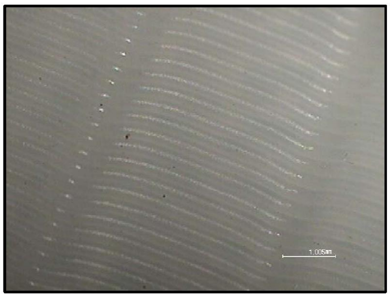


Fig. 2 A theoretical surface roughness distribution

In order to investigate and obtain actual surface roughness distribution, a FDM test part has been fabricated as shown in Fig. 3. The fabrication condition is as follows. The layer thickness is 0.254mm, the applied material is ABS and the processed FDM apparatus is the Maxum. For convenience in measuring the surface roughness by changes of the surface angle, the geometry of the test part is designed as shown in Fig. 3 (a). Fig. 3 (b) shows a magnified photograph by 40s scale for investigating the surface geometry of the test part. Hence, an actual surface roughness distribution was obtained by measuring the surface roughness of the test part as shown in Fig.4. The appearance of the actual distribution is different from that of the theoretical surface roughness according to surface angle changes as mentioned above.



(a) Test part



(b) Magnified photograph in the surface of the test part

Fig. 3 FDM processed test part

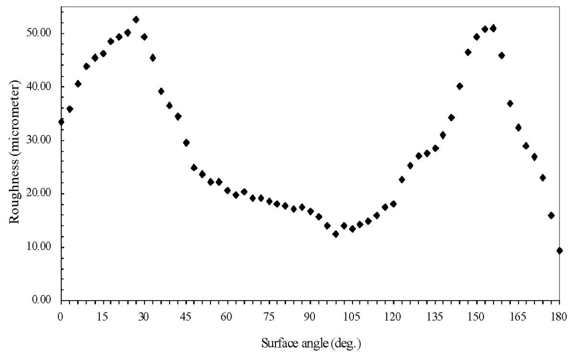


Fig. 4 An actual surface roughness distribution

3. DISTRIBUTION EXPRESSION

Big gaps exist between the theoretical and actual surface roughness distribution as investigated in the previous section. In order to represent actual roughness in computing the distribution, an equation to express the surface roughness distribution is presented. The roughness value ($R(\theta)$) at some surface angle (θ) can be calculated by the Eq. (2). Fig. 5 shows the basis of the Eq. (2).

$$R(\theta) = R(\theta_p) + \frac{R(\theta_n) - R(\theta_p)}{\theta_n - \theta_p}(\theta - \theta_p) \quad (2)$$

Where, $R(\theta_p)$ and $R(\theta_n)$ are the measured roughness values at the previous and next surface angle, θ_p and θ_n respectively, based on the surface angle θ. Thus, the surface roughness values for all surface angles can be obtained with the only limited number of measured values.

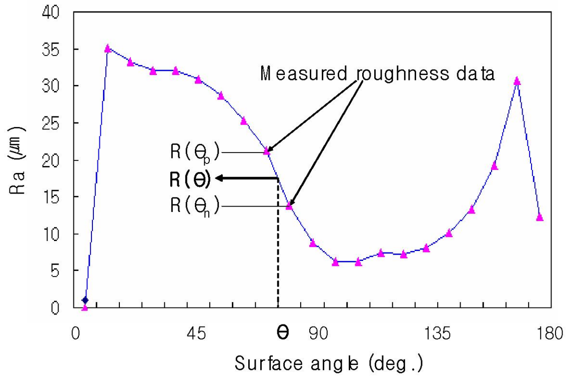
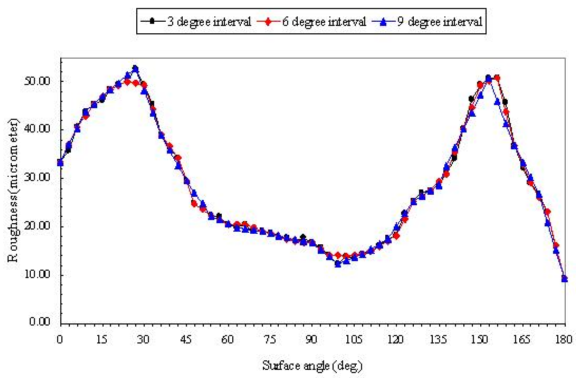


Fig. 5 Computing surface roughness value by measured data and interpolation

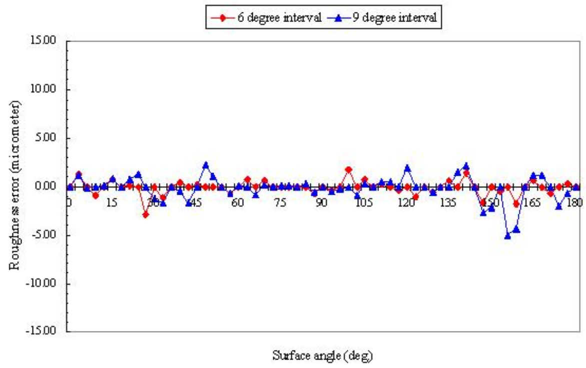
4. IMPLEMENTATION AND RESULT

Because the surface roughness value is calculated by interpolating the measured roughness values using the Eq. (2), the accuracy of the calculated roughness values depends on the number of the measured surface roughness value. In order to obtain reasonable calculated results with the minimum number of the measured value, accuracy estimation in the calculated roughness values by the change of the number of the measured roughness value is required.

Fig 6 shows the calculated results of the surface roughness distribution and error by an interval of 3°, 6° and 9° in surface angle. In each 3°, 6° and 9° interval, the number of the measured roughness values is 60, 30 and 20 respectively. The roughness values measured by the interval of 3° were obtained by measuring the manufactured test part. Taking the measured values with a uniform interval of 3°, 6°, and 9°, and then interpolating the values, each surface roughness distribution curve was generated as shown in Fig. 6 (a). In comparison between the 3° and the 6° interval roughness distributed curve, the two curves are almost similar throughout the surface angle regions. The calculated error values are shown in Fig. 6 (b). The errors are less than 5μm in all surface angles. From the results, it is seen that, if the number of the measured roughness value is over 60, the error can be reduced to less than 5μm. Consequently, considering measurement error, we can obtain reasonable calculated results by the number of the measured roughness 60 data.



(a) Calculated surface roughness distribution



(b) Error distribution

Fig. 6 Accuracy of the calculated distribution

Fig. 7 An applied result by the angle interval with 10 degree

On the basis of the accuracy of the calculated distribution, an applied result is shown in the Fig. 7. In the case, since the interval of the surface angle is 10 degree, the required number of the measured roughness value is just only 10. This result also shows that aver all appearance of the roughness distribution express the actual roughness. Therefore, the proposed methodology can be efficiently used in predicting the surface roughness of the general industrial models which have more than 1 million number of facet.

5. CONCLUSION

A methodology was proposed to express the surface roughness distribution of the FDM processed parts. Theoretical and actual surface roughness distributions were compared to represent the actual roughness distribution. An equation was introduced to express the surface roughness distribution in terms of the surface angle using measured surface roughness data and interpolation. The validity of the proposed approach was demonstrated from the calculated roughness error estimation.

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