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Proposal of a Computational Algorithm for Calculating Material Ratio of Surface Texture†

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Abstract: The material ratio curve (hereafter referred to as MRC) of ISO 13565-2 and ISO 4287 is widely used in industrial fields. The computational algorithm of MRC proposed in ISO has a problem of long calculation time, because of a method of slicing the roughness profile. Therefore, in this study, a sort method was proposed as a computational algorithm for time reduction. However, depending on the form of the surface profile, the algorithm of the proposed sort method has a problem in that calculation errors occur. Therefore, in this paper, we report a new improved algorithm that solves this problem. This algorithm is expected the efficiency improvement of quality control.

Keywords: material ratio curve; Abbott-Firestone curve; roughness; surface texture; computational algorithm

1. Introduction

Surface textures are geometric features that collectively refer to the surface roughness and scratches. This is described in the ISO standard [1]. Since the surface textures are greatly related to the geometrical specifications of the product from an industrial point of view, their quality is required to be controlled quantitatively.

An example of where surface textures play an important role is in bearings. Bearings are used in automobiles, aircraft, and household appliances such as refrigerators and air conditioners because they have the role of preventing energy loss due to frictional resistance by rotating the shaft smoothly.

Because the frictional resistance of a bearing depends on the surface texture, the bearing is closely related to the surface texture.

ISO 4287 [1] contains various surface texture parameters. Typical parameters of surface texture include arithmetic mean roughness *Ra*, maximum height *Rz*, etc. Among them, the material ratio curve (MRC) and MRC parameters can be mentioned as effective methods for evaluating surfaces with excellent lubrication and friction characteristics [2, 3]. MRC is a curve that expresses the ratio of the material and void parts of the surface profile with respect to the height direction. MRC and MRC parameters are used in the industrial world as an effective evaluation method for the quality control of automobile parts and bearings.

A method for calculating MRC from the roughness profile has been proposed in ISO 13565-2 [4]. This calculation method has a problem that it takes a long time to calculate as the number of times of slicing the roughness profile increases. Therefore, in a previous paper [5], the sort method, which is a new MRC calculation algorithm that can shorten the calculation time compared to the ISO standard method, has been reported. However, it was clarified that this calculation method causes problems depending on the profile shape of the measured data [5]. Therefore, in this paper, we report a new improved al-

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gorithm that solves this problem. If the improved algorithm by this research is completed, it can be expected to contribute to the efficiency of quality control in actual industrial sites.

2. The calculation method of MRC by ISO 13565-2

The calculation method of MRC proposed by the ISO standard is as follows: First, a slicing level *ZL* is set parallel to the reference line for the evaluation of the roughness curve. The slicing level is the height of slice (hereafter referred to as the slice height) [4, 6]. Next, the ratio of the material and void parts when the surface profile is sliced at a certain height is calculated, and this calculation is performed sequentially over the whole height direction (henceforth referred to as the slicing method). In this research, the algorithm for calculating MRC with the image shown in Figure 1 [6] is coded using MATLAB.

The procedure of the slicing method is as follows.

1) The slice height is set.
2) The intersection point between the roughness profile and the slice height line is calculated.
3) The length of the material part between the intersections is obtained by linear interpolation.
4) The lengths of material parts *li* are summed over the evaluation length *l*. And then, the material ratio is calculated by dividing the sum of the lengths *li* by the evaluation length *l*.
5) Steps 1) to 4) are performed sequentially, changing the slice height at arbitrary *ΔZ* intervals.

Figure 2 shows an adaptation of the slice method procedure 1) to the roughness profile. The blue line shows the roughness curve (extract) and the red line shows the slice height in Fig. 2. The slicing method has a problem in that it is time-consuming when the number of slicing levels increases.

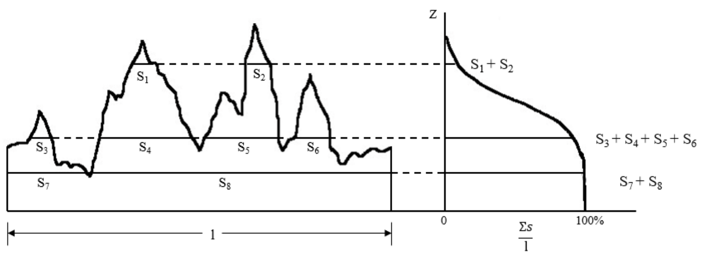


Figure 1. Slice method: derivation method of MRC [4, 6].

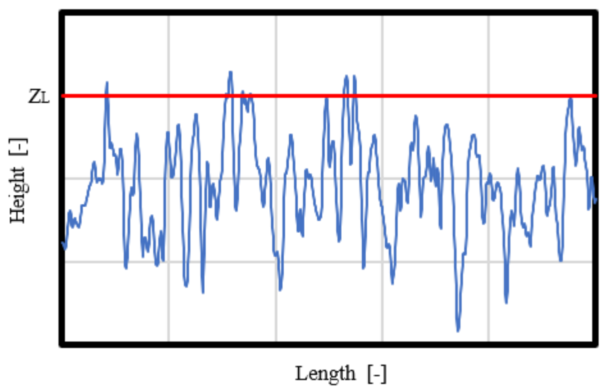


Figure 2. Roughness profile and slice height.

3. New proposed algorithm for calculating MRC

3.1. Sort method for MRC

In this research, the sort method is proposed as a new method of calculating MRC which can reduce the calculation time [5]. The sort method is a method for sorting the height data of the roughness profile in ascending order. Figure 3 shows MRC of the data points sorted by the sort method. The procedure of the sort method is as following steps.

1) Draw the intersection of a horizontal line and a roughness profile at a certain height. The positions of the intersections are then patterned.
2) Calculate the total number of data points that are higher than a certain height value.
3) Repeat step 2), changing the height in descending order.
4) Sort the calculated data points in ascending order.

The measured data of a roughness profile may have the same value of height data. In the sort method algorithm, it was clarified that if the same height value exists in the measured data, counting is performed multiple times, which causes a problem in the calculating of MRC (hereinafter referred to as the overlap counting). The overlap counting is one of the factors that obstructs the correct calculation of MRC in the sort method.

Figure 4 shows MRC where the overlap counting occurs. Since the height values from 0.22 to 0.24% are the same, the sort method results in the same number of data points. Therefore, the values from 0.23 to 0.24% are not output on MRC in Fig. 4. Therefore, this research develops a new algorithm to solve the problem of the overlap counting.

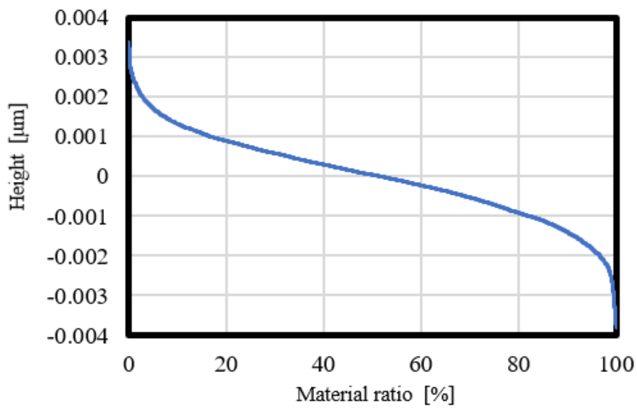


Figure 3. MRC using the sort method.

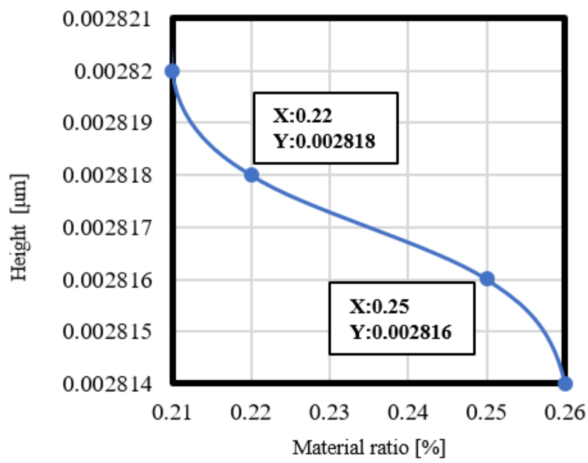


Figure 4. Enlarged view of MRC with overlap counting.

3.2. Improved sort method for MRC

The time to calculate MRC was successfully reduced by using the sort method [5]. However, some conditions need to be satisfied so as to use of the sort method. If the values of the surface profile are randomly arranged as shown in Fig. 5(a), the sort method can be applied. If the sort method is applied to the case in which values of the same height occur consecutively, as shown by the red circles in Figure 5(b), a problem occurs in the derivation of MRC.

Therefore, in this research, in order to solve these problems, we develop an algorithm that does not cause problems in the derivation of MRC even if data with the same height value exists. The green circles in Fig. 6 shows the measured data where the same three values appeared consecutively. In this study, when the same values appear consecutively as shown in Fig. 6, we have developed an algorithm that does not cause problems in the derivation of MRC even if up to three points appear consecutively.

4. Experiment

4.1 Experimental results by the sort method

Figure 7(a) shows MRC calculated by the slice method and MRC calculated by the sort method before the improvement of the overlap counting. Figure 7 (b) is an enlarged view of the part where the overlap counting occurs in Fig. 7 (a). The blue line in Fig. 7 (b) is MRC by the slice method, and the red line is MRC by the sort method. The slice method (blue line) shows that MRC is parallel to the *X*-axis from 0.22 to 0.24%; therefore, measured data with the same height values exist. On the other hand, the sort method (red line) shows that MRC is a diagonal straight line from 0.22 to 0.25%.

The above results show MRC by the sort method is different from that by the slicing method when the measurement data of the same height value exist.

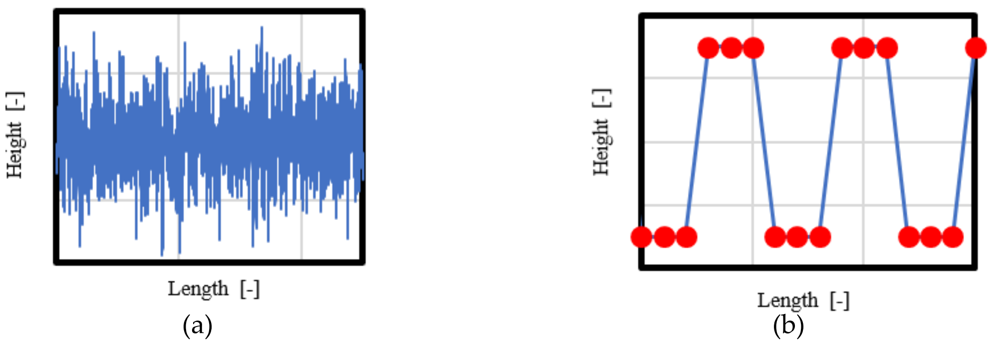


Figure 5. Random and rectangular waves: (a)Random wave; (b) Rectangular wave.

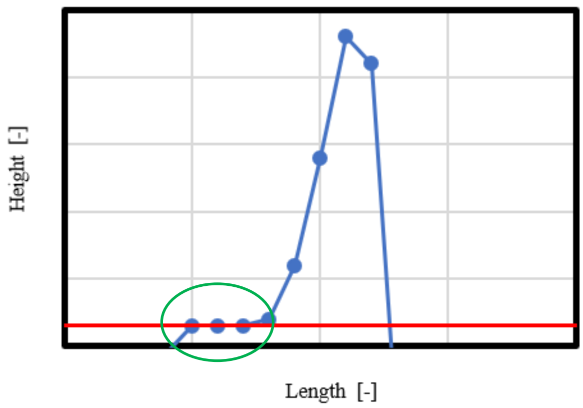


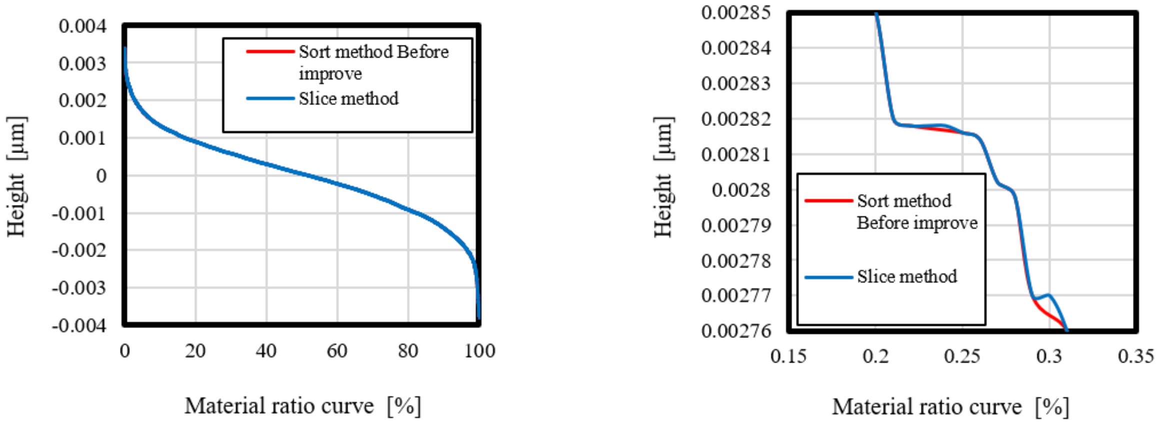
Figure 6. Example of three consecutive points with equal values.

4.2 Experimental results obtained using the improved sort method

In the sort method before improvement, the locations with the same value of height and the locations where the same value occurs consecutively are recorded in a variable by specifying the condition. And, the sort method calculates the number of data points between data points. Therefore, the sort method is improved such that the derivation of MRC does not have problems by modifying the algorithm not to recognize the data points where the same value appears consecutively.

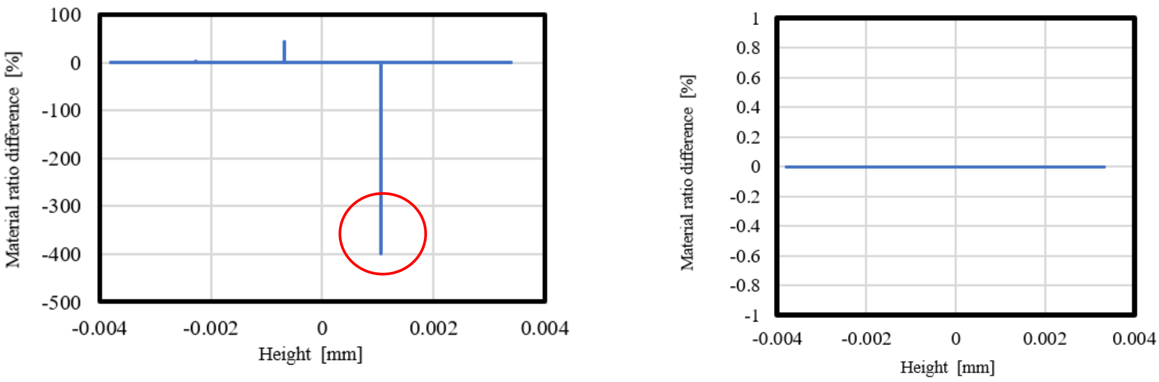
Figure 8(a) shows the deviations between MRC by the sort method before improvement and the theoretical values based on the total number of data points. The red circle shown in Fig. 8 (a) is the error when three same values appear consecutively. Figure 8(a) shows the deviations between MRC by the improved sort method and the theoretical values. The results in Fig. 8(b) show that the error in Fig. 8(a) has disappeared.

From the above results, the development of an algorithm that does not cause problems in the derivation of MRC is succeeded when the same value that appears continuously is up to three. However, if four or more of the same values appear consecutively, a problem still occurs in the derivation of MRC; therefore, further improvement of the algorithm is necessary.



(a) (b)

Figure 7. Comparison of calculated MRCs: (a) MRC by sort method before improvement and slice method; (b) Enlarged view of (a).



(a) (b)

Figure 8. Deviations from theoretical value: (a) Before improvement; (b) After improvement.

5. Conclusions

The results and new knowledge of this study can be summarized as follows:

(1) An improved sort algorithm was developed which solves the problem of the sort method.

(2) The developed improved sort algorithm succeeded in the derivation of MRC without causing problems when the same value appearing continuously is up to three.

(3) The improved sort algorithm caused a problem in the derivation of MRC when four or more of the same values appear consecutively; therefore, we will develop a new sort algorithm to solve these problems in the future.

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