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Investigation and Optimization Flat Lapping Process Using Non-Dominated Sorting Genetic Algorithm II

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ABSTRACT: Lapping process is one of the most important finishing processes in order to achieve a flat surface. In this paper, effects of parameters such as abrasive particle size, abrasive particles concentration in slurry, and lapping pressure on material removal rate, flatness and surface roughness were investigated in single sided lapping of flat workpieces made of 440c steel. To conduct experiments, Lapmaster™ 15 lapping machine has been exerted. The most important problem in lapping process is the low material removal rate which causes increase cost and production time. Therefore, in the lapping process, the selection of conditions that in addition to the production of pieces with geometric accuracy and surface roughness needed have a high material removal rate, is very important. In this paper, for the first time, the material removal rate, surface roughness and flatness lapped pieces have been optimized using non-dominated sorting genetic algorithm II and, the Pareto optimal solutions were obtained. The results show that non-dominated sorting genetic algorithm II is a useful and powerful tool for optimizing the material removal rate, surface roughness and flatness lapped pieces. Using this optimization algorithm, pieces with surface roughness and flatness requirements can be produced at high material removal rate. As a result, with this optimization algorithm, in addition to creating parts with high quality, the production cost and time are reduced.

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1- Introduction

Lapping is a fine manufacturing process in which grains are suspended in a fluid or paste, forming the slurry. The removal of the material is due to the relative movement between the workpiece and the lapping plate. Flat lapping is the most extensively used in industry [1]. Therefore, in this paper, the flat lapping has been investigated. The following is a list of the most relevant researches in this study.

Gullu and Calimli [2] in single sided lapping of flat workpieces made of GG6 cast steel using experimental method have investigated effects of parameters of lapping pressure and time on surface roughness of lapped piece. They concluded that the time of 25 min and the lapping pressure of 689.5 kPa were optimal conditions and the lowest value of surface roughness is observed in these conditions.

Farahnakian and Shahrajabian [3] in single sided lapping of flat workpieces made of AISI 52100 steel using experimental method have investigated the effects of parameters of abrasive particle size, lapping speed, time and lapping pressure on surface roughness and flatness of lapped piece. The minimum surface roughness was 0.051 µm which was obtained in lapping pressure of 7 kPa, lapping speed of 0.164 m/s, time of 15 min and mesh number of 600. The flatness decreased with lapping speed, and was reduced with increasing the pressure, mesh number and lapping time.

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Some of the most important goals of the lapping process are increasing flatness and reducing surface roughness. Increasing the flatness and reducing the surface roughness have a great influence on improve the performance, life span and proper functioning of the workpieces. Although the lapping process has many advantages, but the material removal rate in this process is very low which will increase the cost and production time considerably. Therefore, in this process, the selection of conditions that can, in addition to producing low surface roughness and high flatness, also have a high material removal rate, is very important [4].

In this paper, for the first time, simultaneous optimization of the material removal rate, the surface roughness and the flatness has been discussed and the optimal Pareto has been proposed.

2- Materials and Experiments

Experiments were carried out on the Lapmaster 15 lapping machine (Fig. 1). The workpiece was 440c steel with hardness of 620 HV. The slurry used in the experiments consists of abrasive particles of aluminum oxide mixed with lapping fluid.

In this study, three parameters of abrasive particle size, abrasive particles concentration in slurry, and lapping pressure have been considered as control factors and effects of these parameters on material removal rate, flatness and surface roughness have been investigated.

Fig. 1. Lapmaster 15 lapping machine

3- Results and Discussion

In this paper, MINITAB statistical software has been used for modeling the lapping process. By analyzing the results obtained from the experiments with this software, Eqs. (1) to (3) were obtained for predicting the values of material removal rate, surface roughness and out of flatness respectively.

$$\begin{aligned} MRR = & -1830.68 + 151.414X_1 + 15.1921X_2 + \\ & 86.1742X_3 - 3.71813X_1^2 - 0.064258X_2^2 - \\ & 2.00938X_3^2 - 0.23053X_1X_2 - 0.371307X_1X_3 \\ & - 0.18776X_2X_3 + 0.0116053X_1X_2X_3 \end{aligned} \quad (1)$$

$$\begin{aligned} Ra = & -41.0787 + 17.9912X_1 + 4.51596X_2 - \\ & 11.3308X_3 - 0.38875X_1^2 - 0.0213319X_2^2 + \\ & 0.31125X_3^2 - 0.0195529X_1X_2 - 0.0176977X_1X_3 \\ & - 0.00865976X_2X_3 + 0.000643737X_1X_2X_3 \end{aligned} \quad (2)$$

$$\begin{aligned} F = & 4091.39 - 169.765X_1 + 9.51749X_2 - \\ & 114.383X_3 + 3.20688X_1^2 - 0.0390041X_2^2 + \\ & 2.81937X_3^2 - 0.137749X_1X_2 + 0.247032X_1X_3 \\ & + 0.232042X_2X_3 - 0.000761056X_1X_2X_3 \end{aligned} \quad (3)$$

where *MRR* is material removal rate in nm/min; *Ra* is roughness average in nm; *F* is out of flatness in nm; X_1 is lapping pressure in kPa; X_2 is abrasive particle size in µm; X_3 is abrasive particles concentration in slurry.

The difference between the predicted valuesfor material removal rate, surface roughness and out of flatness and the corresponding values obtained from the experiments have been shown in Fig. 2. According to this Fig, it can be concluded that the values obtained from the experiments have appropriate consistency with the data obtained from the regression model.

In this study, MATLAB software has been used to optimize the lapping process using genetic algorithm technique and the optimum conditions for achieving the highest material removal rate, the lowest surface roughness and the highest flatness of the lapped piece are obtained by this software. Optimum conditions for reaching the highest material removal rate are lapping pressure of 19.4 kPa, abrasive particle size of 89.4 µm, and abrasive particles concentration in slurry of %20.5. Optimum conditions obtained to achieve the lowest surface roughness of the lapped piece are lapping pressure of 10 kPa, abrasive particle size of 16 µm, and abrasive particles concentration in slurry of %18.5. The optimum conditions obtained to achieve the maximum flatness of the lapped piece are lapping pressure of 25 kPa, abrasive particle size of 16 µm, and abrasive particles concentration in slurry of %18.5.

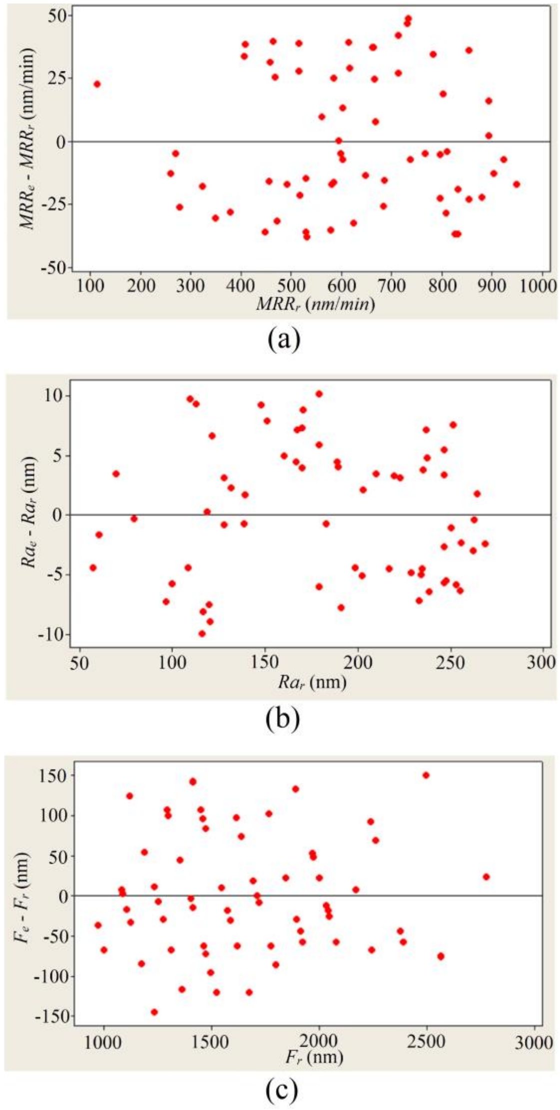

Fig. 2. Difference between (a) *MRR* obtained from experiments and predicted by model, (b) *Ra* obtained from experiments and predicted by model and (c) out of flatness obtained from experiments and predicted by model

The biggest problem in lapping processes, especially when the number of workpieces is high, is the low material removal rate in these processes which will increase the production cost and time considerably. Therefore, in the lapping process, the selection of conditions that can, in addition to the production of low surface roughness and geometric errors, also have a high material removal rate is very important. Therefore, in this study, in addition to the single objective optimization of the lapping process, using a multi-objective genetic algorithm (non-dominated sorting genetic algorithm II), simultaneous optimization of the material removal rate, surface roughness and flatness of lapped pieces have been performed and the Pareto optimal solution is obtained.

In this study, MATLAB software has been used for multi-objective optimization using Non-dominated Sorting Genetic Algorithm II (NSGA II). To achieve the maximum material removal rate, depending on how much the surface roughness and the flatness of the lapped piece are, the lapping pressure, abrasive particle size and abrasive particles concentration in slurry can be selected in the range of 10 to 25 kPa, 16 to 89.65 μm and %17.04 to %20.49.

4- Conclusions

Using non-dominated sorting genetic algorithm II, it is possible to create pieces with surface roughness and flatness required with higher material removal rate. As a result, using this optimization algorithm, in addition to producing optimal quality pieces, production cost and time are reduced.

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