An Experimental Investigation on the Machinability and Lubrication Conditions in Honing Process of Connecting Rods

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***Abstract*—Honing process is the final operation in manufacturing of connecting rods. The surface roughness, dimensional accuracy and the surface texture of the big and small eyes of the connecting rod are dependent to the honing process. In this research, the machinability of the PSA TU3 engine connecting rod is experimentally studied in terms of the effect of rotational and reciprocating speeds and well as the lubrication condition on the tool and work-piece temperature, surface roughness, honing oil consumption, honing tool wear and honing power. The design of experiments is carried out using the response surface central composite method. The results show that the lubrication of the honing tools can excel the machinability of the connecting rods. An optimization is also conducted on the results and the optimum input parameters are obtained. The optimized rotational and reciprocating speeds are also obtained, being 350 rpm and 11.7 m/min respectively.**

***Index Terms*— honing process, connecting rod, tool wear, surface roughness, oil consumption, honing power, workpiece and oil temperature**

I. Introduction

Honing process is a controlled, low-speed sizing and surface-finishing process in which stock is removed by the shearing action to the bonded abrasive grains of a honing stone, or stick [1]. The main characteristic of this process is that the honing tool rotates and reciprocates simultaneously, which produces a crosshatch pattern on the surface. This pattern is useful in some of the applications of honing process.

As the process is a final finishing process, the correct selection of its independent variables such as the rotating speed, the reciprocating speed and the lubrication method are of the utmost importance. Furthermore, the honing tools and honing lubricants are very expensive. Therefore, a comprehensive study on the effects of the input parameters on the dependent honing variables is necessary in order to optimize the output parameters and reduce the process costs.

Several research results are available in the literature. Vrac et al. [2] have investigated the honing process experimentally and determined the most influential parameters during honing process. Chavan and Harne [3] have investigated the process parameters' effects in honing of the cylinder bores. Deshpande et al. [4] have performed an experimental evaluation on the honing stones' grain size and studied the effect if the grain size as well as the other parameters on the surface roughness. Barylski and Sender [5] have worked on the generated heat in honing process. Ma et al. [6] have studied the tribological characteristics of the honed surfaces. Nguyen et al. [7] have carried out an optimization on the honing process and obtained the optimal honing process parameters for best surface roughness and machining time. Kanthababu et al. [8] identified the significant honing parameters and their values for different honing operations. Kanthababu et al. [9] in another work developed a data mining approach for determination of the important honing parameters.

In the present research, the effects of three parameters including the rotational speed, the reciprocating speed and the lubrication method are investigated on the surface roughness, tool wear, work-piece and tool temperature, oil consumption, machining power and machining time. The response surface method is employed for designing of the experiments. The analysis of variance is carried out in order to evaluate the significance of the results.

II. Materials and Methods

The honing machine on which the experiments are carried out is fabricated by Razmyaran Machine

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Manufacturing. The honing tool material was CBN, and the mandrel carried 6 honing stones.

The study was carried out on the honing machine which is employed for honing of the PSA TU3 connecting rod's large eye. This connecting rod is a cutting-type which is manufactured from steel 45M5 UA2 BT. The hardness of the forged material is within 217-255 HBN.

The surface roughness parameters are measured using a Hommel roughness tester T1000. The tool wear was measured using an Easson VMM. The amount of honing stone wear after machining of one connecting rod was negligible, therefore 40 connecting rods were honed with a single setup and the tool wear is then measured. Hence, the values of the tool wear in the results is the tool wear per 40 parts. In order to measure the tool wear, the tool was cooled, cleaned and its dimensions were measured.

The work-piece and tool temperature values are measured using a CEM DT-8835 infrared thermometer. The oil consumption was evaluated using an A&D EW-1500i precision balance. The machine power was measured by a RENAN 5000 meter, which was connected to the power supply of the honing machine. The machining time was measured by a timer.

The response surface method was employed for designing of the experiments. Among different approaches in response surface method, central composite method was employed. Design-Expert 12 software was used for designing the experiments and analysis of the results. Each of the rotational speed and reciprocating speed variables were defined in three levels, and the lubrication method was defined in two levels, namingly, "on-tool" and on-"work-piece". As a result, total 26 experiments were designed. The different levels of the input variables are presented in Table I.

TABLE I. THE INPUT PARAMETERS

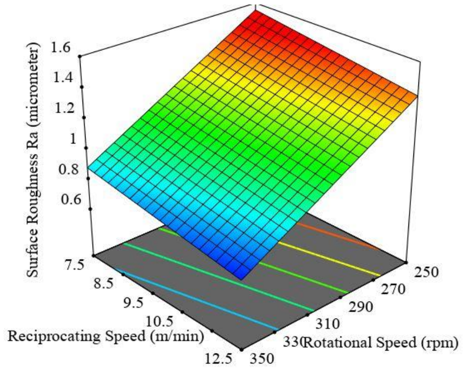
Parameters	Unit	Level 1	Level 2	Level 3
Rotational speed	rpm	250	300	350
Reciprocating speed	m/min	7.5	10	12.5
Lubrication	---	On-tool	On Work-piece	---

Each of the test conditions are applied for 40 work-pieces and the parameters are measured afterward. Two lubrication methods were evaluated in this research: the "on-tool" lubrication, in which the oil flow is applied on the tool via a hole in the holder, and "on-work-piece" lubrication, in which the oil was simply poured on the work-piece.

III. RESULTS AND DISCUSSION

A. The Surface Roughness Results

The surface roughness is measured using two surface quality criteria: Ra and Rz. The results of the effects of the input parameters on Ra is illustrated in Figs. 1a and 1b.



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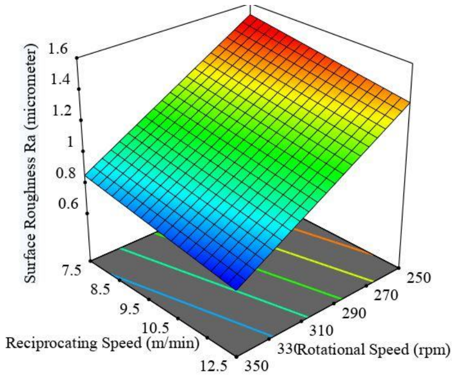

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Figure 1. The surface roughness (Ra) results in on-tool (a) and on-work-piece (b) lubrication conditions

The surface roughness results show that the rotational speed and reciprocating speed have direct effect on the surface quality. The cutting speed in honing is the vector summation of the reciprocating and rotating speeds. It is indicated in previous literature that the surface quality is excelled as a result of the increase in the cutting speed [1]. On the other hand, the lowest surface quality is produced while both rotating and reciprocating speeds were minimum. The results are clearly in agreement with the previous results.

The results show that the lubrication on the work-piece has slightly improved the roughness results in comparison with on-tool results. This could be due to the fact that since the lubricant is poured on the work-piece, it has removed any remained chips from the surface, while when the lubrication is carried out on the tool, there might be remaining chips on the surface which eventually has scratched the surface and increased the surface roughness. It should also be noted that the amount of the differences between these two lubrication methods was not significant.

The surface roughness with the Rz criterion has roughly the same trend. The results are shown in Fig. 2a and 2b.

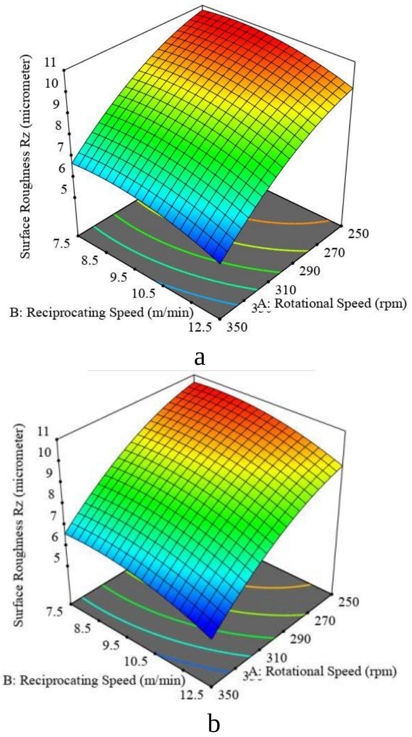


Figure 2. The surface roughness (Rz) results in on-tool (a) and on-work-piece (b) lubrication conditions

B. The Variations in the Work-piece Temperature

The work-piece temperature usually increases as the honing process is carried out. The amount of the temperature rise was highly dependent to the lubrication method. In fact, the cooling efficiency of the tool lubrication was higher than that in work-piece lubrication condition. The results of the effects of the input parameters on the work-piece temperature are presented in Fig. 3a and 3b.

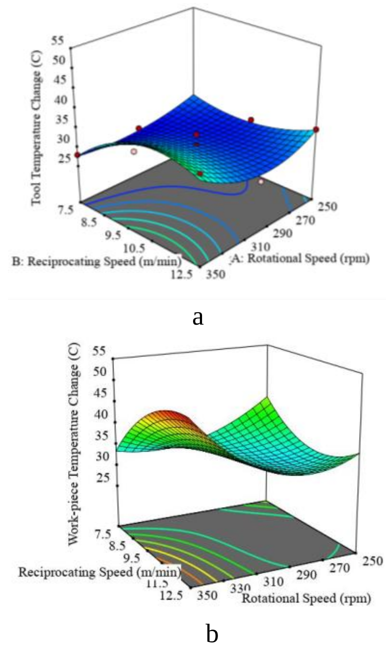


Figure 3. the results of the work-piece temperature in on-tool (a) and on-work-piece (b) lubrication conditions

The results show that the maximum work-piece temperature is occurred in the highest cutting speed (the highest rotational and reciprocating speeds). This is actually true about almost all of the machining processes. As the cutting speed is increased, the cutting zone temperature is increased, as a larger amount of energy is exerted to the cutting zone in higher cutting speeds. However, the work-piece temperature is also increased in lower speeds. This could be the result of decreased lubrication efficiency in lower speeds. The hydrodynamic oil film tends to be thicker in lower speeds, which results in higher friction coefficient between the tool and work-piece. The minimum amount of the work-piece temperature is occurred when these two increasing and decreasing trends have converged to an optimum value.

C. The Variations in the Tool Temperature

The tool temperature roughly follows the trend of the work-piece temperature. The graphs showed that the tool temperature in "on-tool" lubrication condition was noticeably lower than that in "on-work-piece" lubrication condition. The results further showed that the maximum amount of the tool temperature was occurred in higher cutting speeds; while in lower cutting speeds the graphs have a peak. The temperature variations are mainly contributed to the temperature rise in higher cutting speeds, and friction coefficient increase in lower cutting speeds. In Fig. 4a and 4b, the variations in tool temperature are presented.

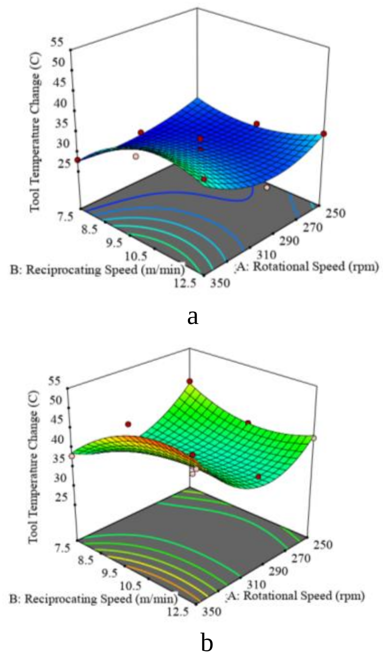
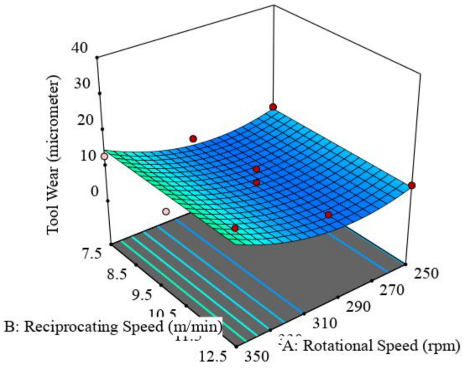


Figure 4. the results of the tool temperature in on-tool (a) and on-work-piece (b) lubrication conditions

D. The Tool Wear Results

The results show that the lubrication of the tool has reduced the tool wear significantly. This is mostly due to the reduced tool and work-piece temperatures as a result of the lubrication of the tool, which was extensively addressed in sections 3.2 and 3.3. The change the lubrication condition from "on-work-piece" condition into "on-tool" condition has eventually resulted in tool wear decline, which was not only due to the improvement in the cooling efficiency of "on-tool" lubrication condition, but also is influenced by excelled lubrication efficiency of the lubricant. It was also observed that the tool wear in the experiments with maximum cutting speeds was the highest value. The graphs had also another peak in the lower cutting speeds, which is contributed to the increased coefficient of friction in lower cutting speeds. In Fig. 5a and 5b, the tool wear results are illustrated.



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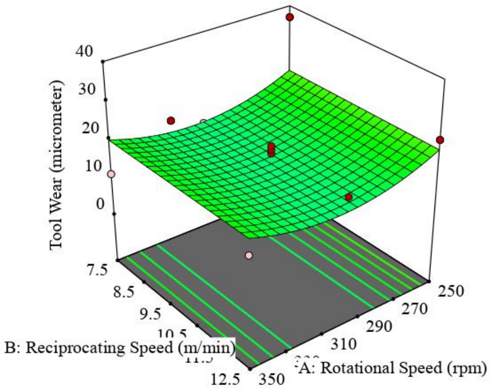

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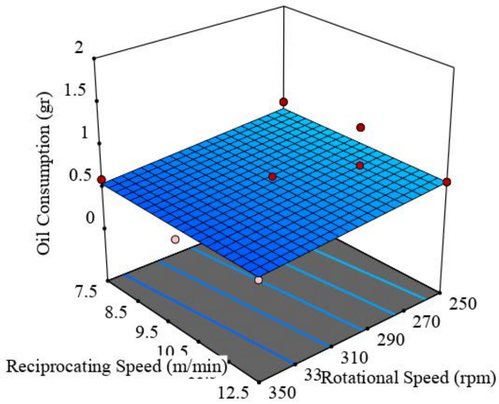
Figure 5. the results of the tool wear in on-tool (a) and on-work-piece (b) lubrication conditions

E. Oil Consumption Results

The results of oil consumption show that the lubrication method has changed the oil consumption significantly. It should be noted that in lubrication of the work-piece, the oil is directly poured on the connecting rods. The parts are transferred to the next operation after honing. The remained oil on the work-piece is therefore wasted, which costs rather high. The tool lubrication pours less amount of oil on the work-piece, and therefore is economically sound. Obviously, the rotational and reciprocating speed have no effect on the oil consumption, therefore the oil consumption graphs, which are presented in Fig. 6a and 6b, are rather flat.



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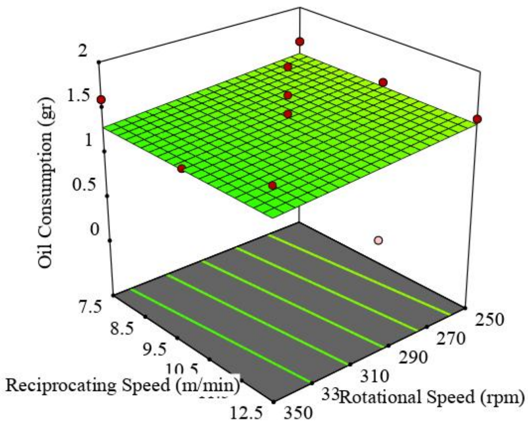

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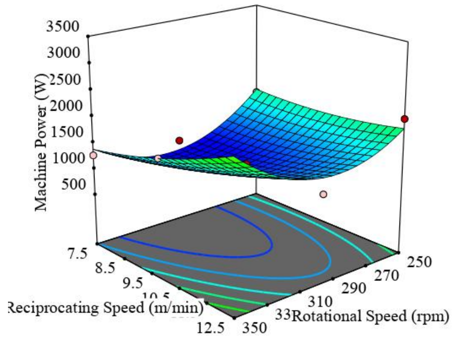
Figure 6. the results of the oil consumption in on-tool (a) and on-work-piece (b) lubrication conditions

F. The Results of Machining Power

The amount of the machine power consumption is presented in Figs. 7a and 7b. The graphs show that the power consumption of the machine in the experiments in which the work-piece was lubricated was marginally higher than that in "on-tool" lubrication condition. This could be due to the improved lubrication condition in the process as a result of tool lubrication. The power consumption values in higher cutting speeds are higher than that in lower speeds, which is logical since both of the speeds are higher. However, the power consumption in lower cutting speeds had also a peak, which could be due to the higher friction coefficient in lower honing speeds.



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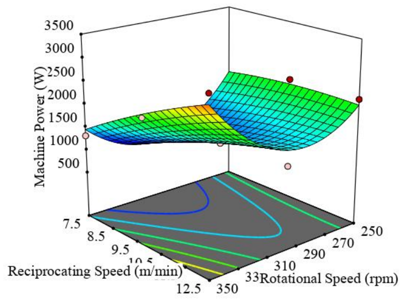

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Figure 7. the results of the machine power consumption in on-tool (a) and on-work-piece (b) lubrication conditions

G. *Optimization of the Results*

The results are further analyzed in order to achieve an optimum point. The importance of the factors are consecutively ranked as the tool wear being the most important factor, the surface roughness parameters are the second most important factors, the tool and work-piece temperature along with the oil consumption are the next important factors, and finally, the power consumption is the least important factor. The results of the optimization in terms of the optimized input parameters and the resultant outputs are presented in Table II.

TABLE II. THE OPTIMIZED INPUT PARAMETERS

Input parameters	The optimized values
Rotational Speed (rpm)	350
Reciprocation speed (m/min)	11.7
Lubrication	On-tool

TABLE III. THE CORRESPONDING OUTPUT PARAMETERS IN THE OPTIMIZED CONDITION:

Output parameters	The values in optimized condition
Ra (µm)	0.745
Rz (µm)	6.099
Tool wear (µm)	14.84
Tool temperature ˚C	38.2
Work-piece temperature ˚C	36.16
Machine power consumption (W)	2105
Oil consumption (gr)	0.534

IV. CONCLUSION

In this research, the effects of the rotational and reciprocating speeds and lubrication conditions on surface roughness, tool wear, work-piece and tool temperature, oil consumption and machining power in honing process were studied. In summary, the following conclusions could be claimed:

- The lubrication method played an important role in improvement of the honing parameters. The tool wear, tool and work-piece temperature and oil consumption are the important parameters that the lubrication on tool excelled significantly. the lubrication on the tool also improved the power consumption modestly. Despite the fact that the surface roughness was slightly increased, the overall results suggest that the "on-tool" lubrication is more beneficial than "on-work-piece" lubrication.
- The increase in the cutting speed was resulted in improvement of surface roughness. However, the cutting speed negatively affect the tool wear and power consumption, and increases the tool and work-piece temperature. As the rotational and reciprocating speeds are both contributed to the cutting speed, the dependency of the results to each of these two speeds are rather identical.
- The optimization showed that the optimized results would be achieved when the rotational speed is maximum, the reciprocating speed is 11.7 m/min and the lubrication is carried out on the tool.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Milad Soleimani proposed the idea and designed the lubrication method. Reza Nosouhi designed the experiments and analyzed the results. He further carried out the optimization. Pouria Pourabedi, Mahmoud Mirkhanzadeh and Ahmad Reza Abadian performed the experiments and measured the output data.

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