Study and prediction of micro-finish of recovered functional surfaces using a developed ECH machine

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Abstract

The aim of the study is to investigate the micro-finish and geometrical accuracy of the recovered functional surfaces made of EN52 material using a newly developed electrochemical honing (ECH) machine. ECH is a prominent hybrid machining process, which is widely used for precision finishing of intricate shapes and hard materials with an efficient and effective manner. In this work, discarded functional surface of the engine valve is recovered using high velocity oxy-fuel (HVOF) technique and its surface topography was studied using developed micro-finish machine. The results show that the ECH of recovered surfaces gives a glazed texture and produce an average surface roughness of 0.96 µm with a processing time of 3 minutes. The monitored outputs such as surface roughness (R_a and R_t), and processing time were also compared with the conventional micro-grinding process to compile the capabilities of the developed machine.

Keywords: Product recovery, HVOF, ECH machine, Micro-finish, Surface quality

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1 Introduction

Surface quality and geometrical accuracy are the most important terms, which will directly affect the service life and performance of the engineering parts. The engine valve is one of such a important part in the engine and its functions is to maintain the combustion chamber pressure tight and gives the passage to inlet and outgases rapidly. They are subjected to high frequency impact at 1400 times/s at a high temperature. Therefore, these valves are functioning over a long period of time under the combined effects of mechanical stress, thermal stress and chemical corrosive stress [1]. The valve faces will be getting erosion and abrasive wear, even resulted in cracking of engine valve [2]. Furthermore, the yield strength of materials decreases, deformation occurs due to repeated cycles impact contact and fatigue failure of materials due to exhaust gas corrosion speeds in terms of cracks and produces abrasive wear of the working surface. From the last two decades, it was noticed that the fuel oil quality deteriorated whereas engine power ratings increase significantly, which has resulted in high thermal loads and a more corrosive environment for a valve and valve seat surfaces [3].

Today scenario, the first preventing method in industrial application is to deposit a special coating on the valve face. This coating has to offer a proper wear resistance, thermal resistance and corrosive resistance on the valve faying face [4]. In addition, it would be useful to upgrade the used valve faces. Therefore, functional properties of engineering components can be, however, recovered and upgraded by using a suitable metal deposition technique on the worn or waste mechanical parts. In general, thermal spray, plasma transformed arc (PTA), laser cladding (LC), bead welding, etc., are used as a material deposition techniques. All these techniques have advantages and disadvantages connected with quality and production cost. Out of them high-velocity oxygen fuel (HVOF) cladding technique is one of the most popular process to deposition process [5]. In this technique, a required coating of material in powder form is heated rapidly in a medium of hot gases. Simultaneously the heated powder material particles are then projected at a high velocity onto a prepared substrate surface, where it builds up to generate the required coating [6]. The last decade, HVOF sprayed coatings have been widely used in industrial applications, aerospace, marine and power plants, because it gives a low porosity and oxide content, high hardness and high adhesion coating [7]. It has ability to accelerate the melted powder particles of the feedstock material at a relatively large velocity as compared to other thermal techniques [8-10]. Moreover, because of its key ability to bond many materials together, it becomes a famous technology for recovering parts. Therefore, for this phase good machinabilty is an important aspect of deposit coating.

Traditionally, grinding process is applied to finish the top-surface of the deposited layer specially required for mating surfaces, i.e. valve face, crankshafts, etc. The major disadvantages of the grinding process is that it suffers from low finishing rate, high tool wear, and high probability of surface damage due to point forces on the deposited layer [11, 12]. The hardness of the deposited layer act as a determining factor and even sometimes such layers are very difficult-to-machine using conventional methods. Therefore, there is a need for an alternate process which has the capability of nano-level finishing at higher finishing rate. The process is expected to be effective for finishing intricate external profiles and advanced materials. In the recent years, electrochemical honing (ECH) is emerging as a prominent finishing technique for both internal and external surfaces [13].

To date no work has been reported on finishing of HVOF clad layers using ECH process. This paper presented a comparison study of recovered part working surface using micro-micro-grinding and ECH process, to better summarize the process capabilities of these processes over deposited material. The aim of this work was to upgrade and recover the discarded engine valves to like-new performance. The surface properties, such as microstructure, surface roughness and the design properties such as geometrical accuracy and profile dimensions have been investigated.

2 Experimental Procedure

The details of the experimentation is consists of two phases namely workpiece selected and material and development of the ECH machine. For the present study, discarded engine valves were collected, those are required around 300 microns layer of material deposition to meet the original dimensions. The deposition of the material has been done by using HVOF process. The average thickness of the deposited cladding was 400 microns. Therefore, to meet the original dimensions 100 microns thickness should be removed by the finishing process. Figure (1) describes a view of compound engine valves prior to finishing. Table 1 presented the chemical composition of working surface of valve after HVOF cladding that were observed through a BAIRD made atomic absorption spectroscopy instrument. The average surface roughness (Ra) and maximum surface roughness (Rt) of the recovered surface using an optical profilometer were observed 7 µm and 35 µm respectively.

Figure 1: Compound engine valves prior to finishing

Table 1: Chemical composition of the engine valve face

Element	C	Cr	Mn	Si	S	P	Fe
Weight (%)	0.44	9.5	0.67	3.24	0.038	0.04	balanced

On the other phase, ECH machine is developed with the objectives to provide an alternate for higher finishing rate, excellent surface quality and high geometrical accuracy. The photographic view of the developed ECH process for precision finishing of recovered surfaces of engine valve face is depicts in Fig. (2). This setup has four subsystems namely (i) finishing chamber housing workpiece, cathode and honing tools; (ii) electrolyte supply system; (iii) power supply system; and (iv) rotation system to the tooling system. In this process, most of the metal is removed at the atomic scale by electrolytic dissolution. Moreover, the honing action as well acts as performance multiplier.

In ECH process, the workpiece is connected with the positive terminal and the tool is connected with the negative terminal of the power supply system and a small DC electric potential across them is applied. The inter-electrode gap (IEG) between the workpiece and tool around the ECM zone is filled with the full streams of electrolyte and an applied current is passed through them. During the process of material removal from the workpiece, oxygen is evolved out at cathode after dissolution of aqua solution and this oxygen reacts with anodic workpiece gear to form a thin metal oxide micro-film on workpiece. This micro-film is insulating in nature and protects the workpiece surface from being further removed and it minimizes the ECM action. This oxide layer on the surface of the workpiece gear is scraped by the honing action when it comes in contact with honing tool. The honing tool was spring loaded and help to complete scrubbing of the workpiece surface. This scrubbed surface, when returning to the ECM zone, is removed electrochemically once again. The surface quality and geometric accuracy of the workpiece surface is rapidly improved as the process continue.

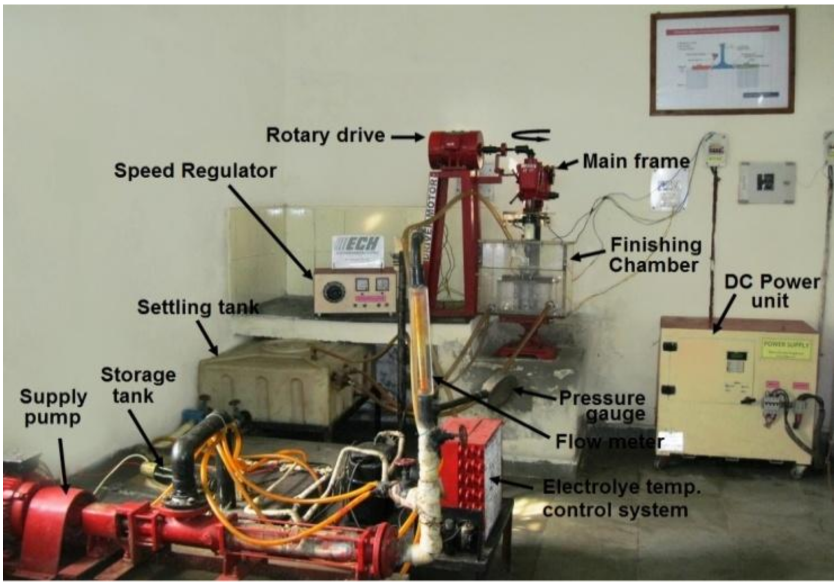

Figure 2: Photographic view of the developed ECH setup

Table 2: Details of the variable input parameters

Current (A)	20	30	40	50	60
Processing time (min)	Profile dimensions are checked after every 20 sec of processing time and fixed where profile error is minimum				

Table 3: Details of the fixed input parameters

Parameters	Values	Criteria of selection
Voltage	30 V	Pilot study
IEG	0.6 mm	DOE study
Cathode material	Copper	Literature review
Composition	80 % NaCl + 20% $NaNO_3$	Pilot study
Concentration	7.5 % (by Volume)	DOE study
Temperature	34^0 C	Pilot study
Flow	15 lpm	Literature review
Honing material	NiCr	Literature review
Rotary speed	70 rpm	Pilot study
Abrasive size	50-75 µm	Literature review
Honing Pressure	0.02 MPa	Literature review

For the present study processing time and current used as an input process variable to investigate the effect of ECH on the clad surfaces by analysing the surface roughness, morphology finished surface and geometrical accuracy before and after the process. The range of input variables for ECH process has been presented in Table 2. The processing time is increased at the interval of 20 seconds for each value of current and fixed where the profile error is minimum. The profile dimensions are checked and compared with the original engine valve profile. The profile error is calculated based on the difference in the profile area between the original (designed) part and finished workpiece (remanufactured). The values of the fixed variables were selected based on the literature review, machine constraints and the pilot experimentation as described in Table 3.

3 Results and Discussion

The experimental results of ECH of recovered surfaces of the engine valve face have been presented in the following section. During the analysis of the results, the main attention was focused on the improvements in the surface roughness and profile dimensions of the workpiece. Table 4 presents the values of input parameters and the responses of the different experiments. The effect of current on the average surface roughness and maximum surface roughness was depicted in Fig. (3).

It is observed from these results that the best combination of responses was achieved for experiment no. 2 having parametric combination of current 30 A; and processing time as 3 min. Hence, 3 min was selected as an optimum processing time and 30 A was selected as appropriate amount of input current. Figure (4) illustrate the surface topographies of the workpiece surface before finishing and after finishing using ECH. It is clear from the figures that the surface texture of the finished workpiece by the ECH appears glazed indicating significant improvement in surface finish. It was observed that there was a 84 % improvement is the workpiece surface after finishing the part through ECH.

The SEM analysis was also conducted on workpieces to investigate the morphology of finished surface. Fig. (5) clearly show that before finish, the work surface contains voids, porosity, pits etc. ECH processed surface shows a uniform and smooth appearance. The asperity heights were removed due to the combined action of ECM and honing process. It is observed that the abrasive feed marks are not visible in the ECH processed surface due to the existence of low honing pressure in ECH as compared with micro-grinding conditions.

Table 4: The values of input variables and the responses of the different experiments

Run no.	Current (A)	Processing Time (min)	Profile error (mm^2)	Ra (μm)	Rt (μm)
1	20	3.5	- 0.22	1.25	9.16
2	30	3	+ 0.15	0.96	8.94
3	40	2.5	- 0.25	2.04	10.68
4	50	1.75	+0.47	2.73	11.24
5	60	1	+0.14	2.81	11.57

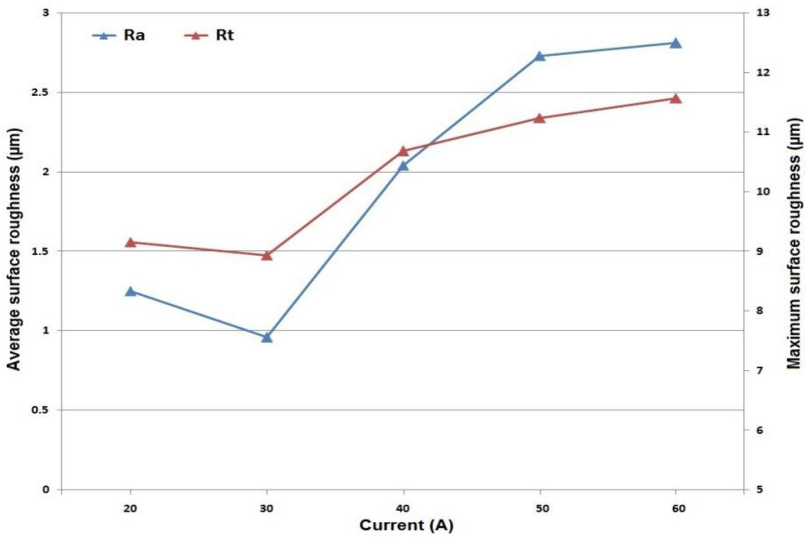

Figure 3: Plot Ra/Rt - current

Based on the literature review on the finishing of recovered surfaces using the conventional methods like micro-grinding, it is confirmed that the ECH can produce a better surface roughness of the workpiece than the micro-grinding. This will improve the service performance and it can say that any hardness of the material can be processed efficiently. The comparison of the present work with some past work has been illustrated in Table 5. Moreover, it is found that the micro-grinding process can only finish the one surface at a time with a given set of grinding wheel and workpiece surface. To finish the other relevant faces of the valve, the whole setting is modified. In ECH, multiple setting is not required to finish the geometry of the valve face because designed cathode tool has the capability to finish the workpiece geometry in a single setting..

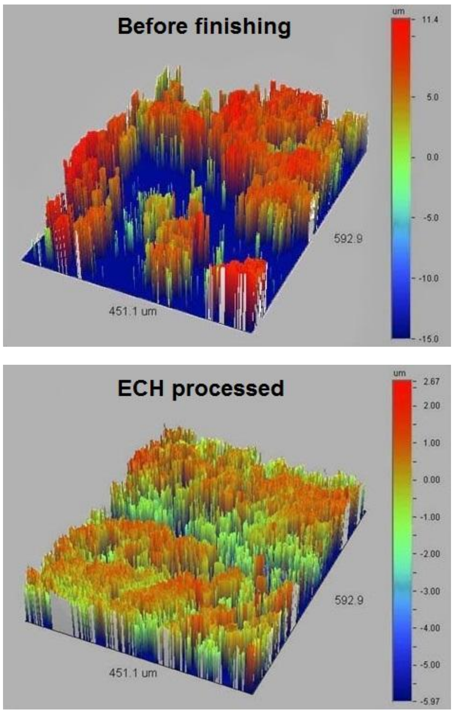

Figure 4: Topography of the workpiece surfaces obtained through optical profilometer

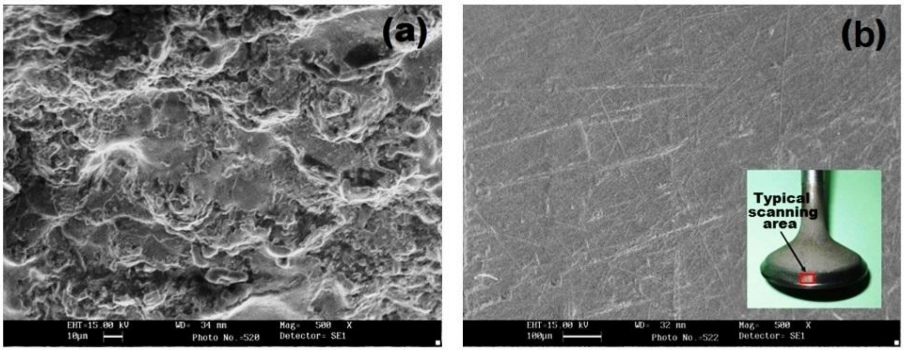

Figure 5: Typical SEM micrographs (a) prefinished; (b) after ECH

Table 4: The values of input variables and the responses of the different experiments

Ra	Rt	Processing Time	Process	References
0.96 µm	6.94 µm	3 minutes	ECH	Present Work
Nil	4 to 5 µm	Nil	Micro-grinding	Kubohori (2007)
0.85 µm	5.13 µm	6 minutes	Micro-grinding	H.Singh (2014)

4 Conclusions

Summarizing we can conclude that, in this study, alternative machining processes were developed, in order to prepare a defect free, smooth, geometrical accurate profile and high finish workpiece surface for a subsequent ECH process and its results are compared with micro-grinding process. The following conclusions could be drawn based on the comparative analysis.

(1) ECH process provides stress and thermal damage free finishing operation at higher finishing rate. The ECH of precision finishing of clad surfaces takes 50 percentage less processing time as compared with micro-grinding.
(2) This study shows that a complete profile of the workpiece was finished in case of ECH process depending on the specific geometry of the ECH cathode tool. But in case of micro-grinding process, only valve head faying face is finished in a single turn which made the ECH process further efficient.
(3) ECH of recovered surfaces gives an average surface roughness of 0.96 µm, which is significantly lower as compared with the micro-grinding process.
(4) It is reported that the micro-grinding of recovered surfaces of engine valve face have a high tool wear and abrasive marks on the processed surface.
(5) It is reported that the ECH finished surface have no deep feed marks, microstructure is more uniform and smooth as compared with finished surface by micro-grinding.

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References

[1] S. Qixian, S. Yan, "Development of laser cladding stellite alloy on valve face," Seoul 2000 FISITA World Automotive Congress, Seoul, Korea, 2000.
[2] D. Schlager, C. Theiler, H. Kohn, "Protection against high temperature corrosion with laser welded claddings applied and tested on exhaust valve discs of large diesel engines burning heavy fuel oil," International Journal of Materials and Corrosion, vol.53, pp.103-110, 2002.
[3] S.K. Nando, A.P. Roskilly, "Exhaust valve failure under residual fuel operation," International Journal of Marine Design and Operations, No. B2, pp. 23-28, 2003.
[4] A. Klimpel, L.A. Dobrzanski, A. Lisiecki, D. Janicki, "The study of the technology of laser and plasma surfacing of engine valves face made of X40CrSiMo10-2 steel using cobalt-based powders," International Journal of Materials Processing Technology, vol.175, pp.251-256, 2006.
[5] H. Herman, S. Sampath, R. McCune, "Thermal spray: current status and future trends. materials research bulletin," vol.25(7), pp.17–25, 2003.
[6] D.E. Crawmer, *Thermal spray processes*, In: Davis, J.R. (ed.), Handbook of Thermal Spray Technology, ASM International, Materials Park, pp.54-76, 2006.

[7] L. Pawlowski, *The Science and Engineering of Thermal Spray Coatings*, 2nd edn., Wiley, Chichester, pp.85-89, 2008.
[8] J.R. Davis, *Handbook of Thermal Spray Technology*, ASM International, Materials Park, pp.175-213, 2006.
[9] E. Dongmo, M. Wenzelburger, R. Gadow, "Analysis and optimization of the hvof process by combined experimental and numerical approaches," International Journal of Surface and Coatings Technology, vol. 202, pp.4470-4478, 2008.
[10] S, Kamnis, S. Gu, T.J. Lu, C. Chen, "Computational simulation of thermally sprayed WC-Co powder," International Journal of Computational Materials Science, vol. 43, pp.1172–1182, 2008.
[11] P.N. Moulik, H.T.Y. Yang, S. Chandrasekar, "Simulation of thermal stresses due to grinding," International Journal of Mechanical Sciences, vol.43, pp.831-851, 2001.
[12] J.A. Picas, A. Forna, G. Matth, "HVOF coatings as an alternative to hard chrome for pistons and valves," International Journal of Wear, vol.261 pp.477-484, 2006.
[13] H. Singh, P.K. Jain, "Remanufacturing with ECH - A Concept," International Journal of Procedia Engineering, vol.69, pp.1100-1104, 2014.
[14] T. Kubohori, Y. Inui, T. Ikuta, "Evaluation of grinding characteristics of thermal spraying ceramics film," International Journal of Materials Transactions, vol.48(5), pp.1050-1054, 2007.
[15] H. Singh, P.K. Jain, Finishing characteristics of Plasma and HVOF cladding**,** Proceeding for International Conference on Advances in Materials, Manufacturing and Applications (AmmA - 2015), NIT Trichy, April 9-11, 2015, pp. 48.