Electrochemical Honing of Mating Clad Surfaces - A Concept towards Remanufacturing Engineering

H. Singh, and P.K. Jain

***Abstract*—** A concept of remanufacturing is developed for expensive saving of raw materials, because it consumes only a fraction of the material, cost and energy required for new parts. The requirements of remanufacturing techniques increased significantly in recent years as landfill and incineration capacity is being depleted. A dramatic reduction in environmental impact can be made by product remanufacturing in which, in contrast to material recycling, the geometrical form of the product is retained and its associated economic and environmental value preserved. Various cladding techniques are used to recover worn-out parts. A drawback of cladding techniques is the poor surface finish, which requires further finishing of the mating surfaces of the part. Electrochemical honing (ECH) is a hybrid micro-finishing process and have their own advantages to remove any hard material with controlled surface generation with excellent surface finish. Furthermore, it provides highest productivity and increasing the service life of critical components. This paper presents a unexplored concept with some directions for future research with an objective to mature the remanufacturing engineering and enhances the capabilities of ECH.

***Index Terms*—** electrochemical honing (ECH), laser cladding, remanufacturing, surface quality, precision finishing

I. Introduction

Remanufacturing has been called the ultimate form of recycling worn parts. Owing mainly to the saving of expensive materials of new parts [1]. The cost of spare parts for aerospace and automobile engine are very high, in many cases repair of parts is cost effective. A lot of components are reused, which results in decreasing the amount of material, energy and waste [2]. Therefore, remanufacturing makes components more broadly available at lower prices. Compared to new products, remanufactured products cost only 50% of new products, while 60% of energy and materials 70%.

At present the main preventive measure in industrial application is to deposit a layer on worn parts with wear resistance, corrosive resistance and thermal resistance [3]. There are some layer deposit techniques such as shield metal arc (SMA), metal inert gas (MIG), submerged arc (SA), tungsten inert gas (TIG), high velocity oxy-fuel (HVOF) and laser cladding etc. These techniques have their own disadvantages of quality assurance and production cost to a certain level. One of the techniques that overcomes these problems is laser cladding. The laser cladding technique is employs laser beam of high energy density, melting and solidifying quickly the materials differential in physical and chemical properties on the matrix surface, then obtaining the layer in properties differential compared with matrix properties. The laser cladding technique provides fine crystalline grain, close microstructure and strong bonding strength of deposited layer [4].

One of the most critical issues is that laser clad surface have a deleterious surface finish which, systematically requires post machining steps. In the recent years, few reports to control the surface roughness by adjusting and optimizing processing parameters using different design methodologies or by applying different approaches during and after the laser cladding were presented [5], [6]. The current status of the laser cladding specially with mating surfaces is insignificant. Therefore, post machining is essential to achieve sufficient surface quality. Generally, conventional grinding process is used initially under controlled conditions to remove small material and then to achieve micro finish, abrasive polishing or lapping process is applied on the clad surface. But continuous embedded point forces through grinding wheel were causes surface failures in the clad surfaces. This manuscript presents the unexplored concept to mature the remanufacturing engineering by dealing ECH precision finishing process with clad surface. ECH have their own advantages to remove any hard material with controlled surface generation with excellent surface finish.

II. Literature Review

The ECH concept of taking help of electrolyte dissolution to improve the performance and productivity of mechanical honing evolved during 1963-1965 [7]-[9]. Randlett and Ellis compared the mechanical honing with ECH processes and suggested the successfully tested electrolyte for different materials and machining time variation between two processes for different materials [10]. In the ISEM-7 research article, Budzynski presented the results of optimization of ECH of cylindrical holes that were considerably deformed by heat treatment using ammonium nitrate as electrolyte. This work was a first attempt at the optimization of ECH process. Several input variables; current density, machining rate, honing pressure of abrasive sticks etc. and output parameters; shape deviations, average and maximum surface roughness etc. were studied. This study revealed that current density, honing unit pressure, and machining time were significant parameters in material removal, but these parameters does not influence the shape deviations and surface finish. Budzynski presented his

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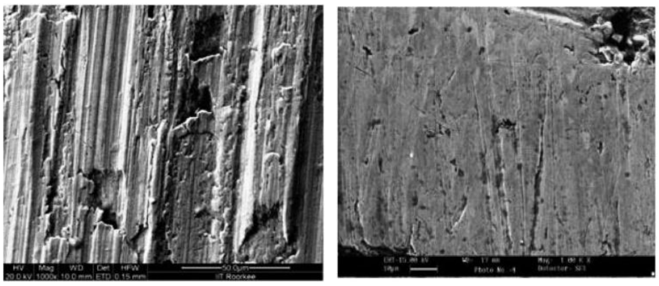
pioneering work on ECH of cylindrical holes in subsequent papers [11], [12]. The application of ECH for gear teeth finishing was first reported by Chen in 1981. Since material removal in ECH is governed by Faraday's law of electrolysis, the amount of the material removed and consequently the accuracy of the gear profile can be controlled either by controlling the amount of the current passed or by varying the duration of time [13]. Jianjun [14] reported the use of pulse power supply in ECH to improve the result than ECH under continuous current by providing relaxation period to the machining process during pulse-off time. In the recent years, various aspects of ECH were presented to enhance the process performance. The most of the researcher concluded that the ECH process is feasible for precision finishing of mating components, and the process can provide a fine finished surface with a very uniform spread of surface roughness values. "Figure 1" shows the improvement in microstructure before and after ECH [15].



(a) (b)

Fig. 1. SEM photograph: (a) before ECH (at 1000x); (b) after ECH (at 1000x) [15]

Therefore, the past work revealed that ECH is an ideal choice for precision finishing, improving the surface integrity and increasing the service life of the critical components, such as internal cylinders, transmission gears, carbide bushings and sleeves, rollers, petrochemical reactors, moulds and dies, gun barrels, etc., most of which are made of very hard and/or tough, wear-resistant materials generally susceptible to heat distortions. Therefore, ECH has capabilities and potential to overcome most of the limitations of conventional finishing methods and at the same time offers high productivity [16]. Table I describes the ECH process capabilities by comparing with conventional grinding process.

TABLE I: A COMPARISON OF GRINDING AND ECH PROCESS OUTCOMES

Process	Surface Finish (μm)	References
Grinding	2-3	Kubohori (2007), Goeke (2012),
ECH	0.05	Bendict (1987), Dubey (2008)

Remanufacturing has a history of more than 50 years in some developed countries, a complete remanufacturing system forms from technical standards, processing technique, fabricating machinery to reverse logistics and delivery. Most of the past work agrees that remanufacturing is environmentally efficient and profitable [17], [18]. Robert Lund is the pioneer of remanufacturing industry, and he has made observable contributions on this area. He believes that remanufacturing is the recycling at components level, it retains the value-added in the components [19]. Ming found that remanufacturing an engine can save 55 kg steels, 8.3 kg aluminium and 113kWh electric powers and reduce emissions of 565 kg CO_2, 6.09 kg CO, 1.01 kg NO_x, 3.985 kg SO_x and 288.725 kg solid waste. The demand for remanufactured products will increase in the coming years as the end consumers become more aware of climate change and its impact.

Previous research on remanufacturing has addressed a variety of problems, and we summarize the efforts relevant to remanufacturing of engine parts, those are required highly surface finish to reduce the wear and friction of the parts like exhaust valve, valve seat, gears, cylinder linear, shafts, guide block etc. The engine remanufacturing industry will probably become a position in market dealing with disasters, vintage vehicles, etc. This is a useful and profitable side of things, but it is significantly smaller. Engine valves are subjected to high frequency impact at 1400 times/s at high temperature at 500 ^{o} to 800^o C. Therefore, the service condition of the engine valve is very deteriorative. The valve face will be getting erosion, corrosion and abrasive wear, even resulted in cracking of valve face. For remanufacturing by recoating of worn engine valve, Aihua found that laser beam cladding of seating surfaces on exhaust valve was avoid discontinuities such as porosity and cracks. A coating with finer microstructure, more narrow heat-affected zone and higher micro-hardness value can be obtained with the laser cladding. Impact wear test and engine test both show that laser cladding of valves can improve the properties of valves [20]. Later on, many researcher were reported laser cladding of engine valve by using different clad materials which ensures higher precision of control of heat

(a) (b)

Fig. 2. A view of engine valve face: (a) Erosion wear (22); (b) after LC (23)

input and by this the deposit quality, shape and dilution in compared to plasma power surfacing (PTA) surfacing or vacuum induction fused (VIF) surfacing [21]-[23]. A view of worn out engine valve face and laser cladding of engine valve face shown in "Figure 2". Wlodzimierz reported that laser cladding obtained layer have little distortion of the material and it increased the average R_{tm}. Gharbi and Rombouts [24] presented the poor surface finish issues, which are the one of the main limitation of the laser cladding process. They showed that the use of thin additive layers, and large melt-pools improve surface finish, and that increased powder/laser interaction distances, resulting in particle melting were also beneficial factors for surface finish. They predicted R_a value of laser cladding surface in the range of 30 to 110 μm. Qin reported the effect of laser cladding on surface roughness which indicates that overlap ratio during cladding was the main factor to affect the surface roughness. The R_a value increases with the increase of overlap ratio and slicing thickness.

III. CONCEPT

The research objective is to provide an alternate to overcome poor surface finish problems of clad surfaces. The concept focus on development of a remanufacturing of engine valve face. The valves in an engine have numerous function rapidly, the proper mating of valve faces with valve seats will require to avoid leakage, and to improve the service performance. The poor surface finish of the laser clad valve face can be improved by using ECH process. The ability of ECH to micro-finish of any conductive hard material with stress free surface generation and geometrical correction of parts promises to useful outcome that mature the remanufacturing engineering. The chemical composition of worn-out exhaust engine valve is examined by using spark emission spectroscopy analysis as listed in "Table II". Based on the percentages of chemical composition, EN 52 alloy steel is identified as an engine valve material. EN 52 alloy steel was not deals until now with ECH process. Therefore, the research objective in addition enhances the capabilities of ECH process.

TABLE II: CHEMICAL COMPOSITION OF ENGINE VALVE FACE (WEIGHT, %)

C	Cr	Si	S	N	Mn	S	P
0.47	9.2	3.46	0.34	0.37	0.39	0.042	0.029

IV. EXPERIMENTAL SETUP

The application of ECH for precision finishing of engine valve face or clad surface has not been given due attention so far and as a consequence probably no such experimental setup has been reported neither from the research community or from the mechanical industries. Therefore, based on the objectives of study, design consideration and economic feasibility, an experimental setup for the same has been designed and developed. The developed machine setup consists of four major subsystems: power supply system, electrolyte supply system, tool and tool-motion system and machining chamber and fixtures. The schematic diagram of working principle of ECH of coated part will be designed as shown in "Figure 3" and diagram of designed machining chamber with front and top views as shown in "Fig. 4".

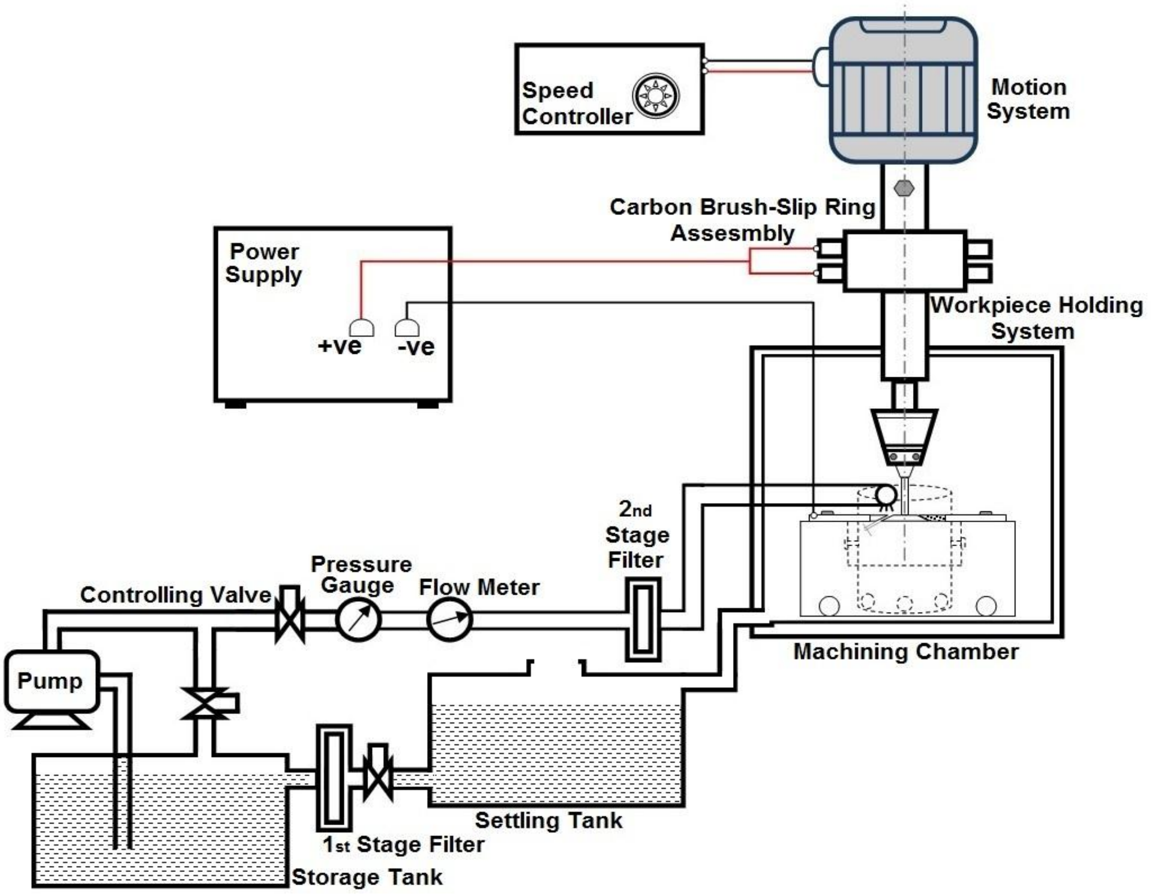


Fig. 3. A schematic diagram of designed experimental setup for remanufacturing of engine valve face through ECH

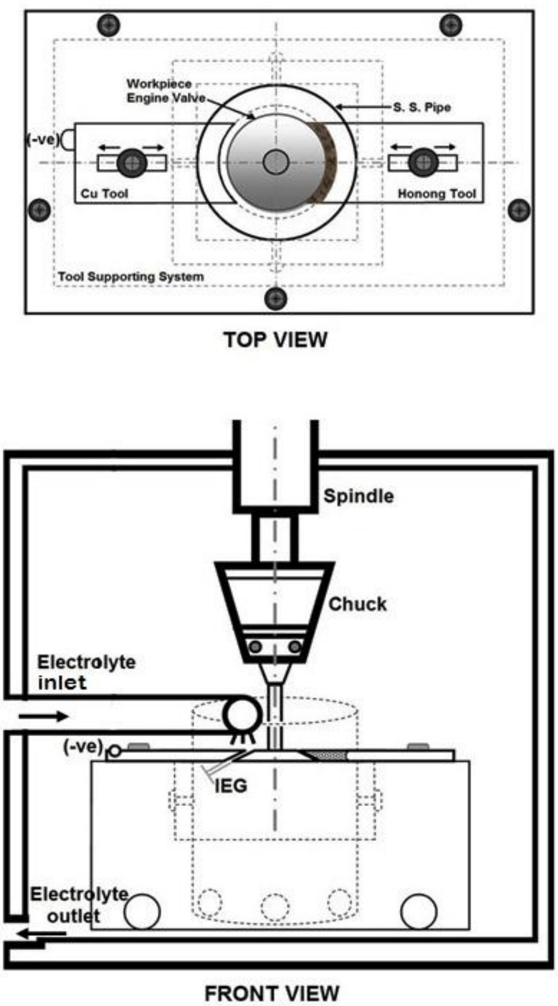


Fig. 4. A schematic diagram of machining chamber with tools and positioning systems in ECH of valve face

The workpiece (engine valve) is made as an anode and the tool is made as a cathode by applying a small DC electric potential across them. The inter-electrode gap (IEG) is maintained between workpiece and the tool to avoid shot circuiting, and filled with the electrolyte. During this, non-conductive spring controlled honing tool is applied with equal pressure on the workpiece. The honing tool has a harder abrasive coating compared with workpiece clad material to act as scrubbing element to remove the insulating layer of metal oxide [7]. The mechanism of material removal in ECH is based on the interaction between electrolytic actions with mechanical abrasion. It is reported in the literature that more than 90 per cent of the material removal occurs through electrolytic action, and remaining material and oxide layer removal occurs through mechanical honing action [16]. Figure 5 describes the proposed working principle of the ECH of engine valves.

V. Conclusion

Remanufacturing of engine parts is in the preliminary stage and therefore, a sustained global research is mandatory to meet the surface quality as good as for new components. Now-a-days, remanufacturing techniques are unable to produce the precision surface finish as required for matching parts. Therefore, the challenge we need to overcome is how making promoting method suiting the finishing of hard clad surfaces. From the literature survey presented in this paper, it is very clear that the ECH process is one of the ideal choice to defeat the surface problems occurs during finishing of clad surfaces by machining (grinding) process. Present aspect, which is unexplored, is the use of the ECH process for remanufactured engine components which can improve dimensional accuracy and surface characteristics of the deposited layer in a single action.

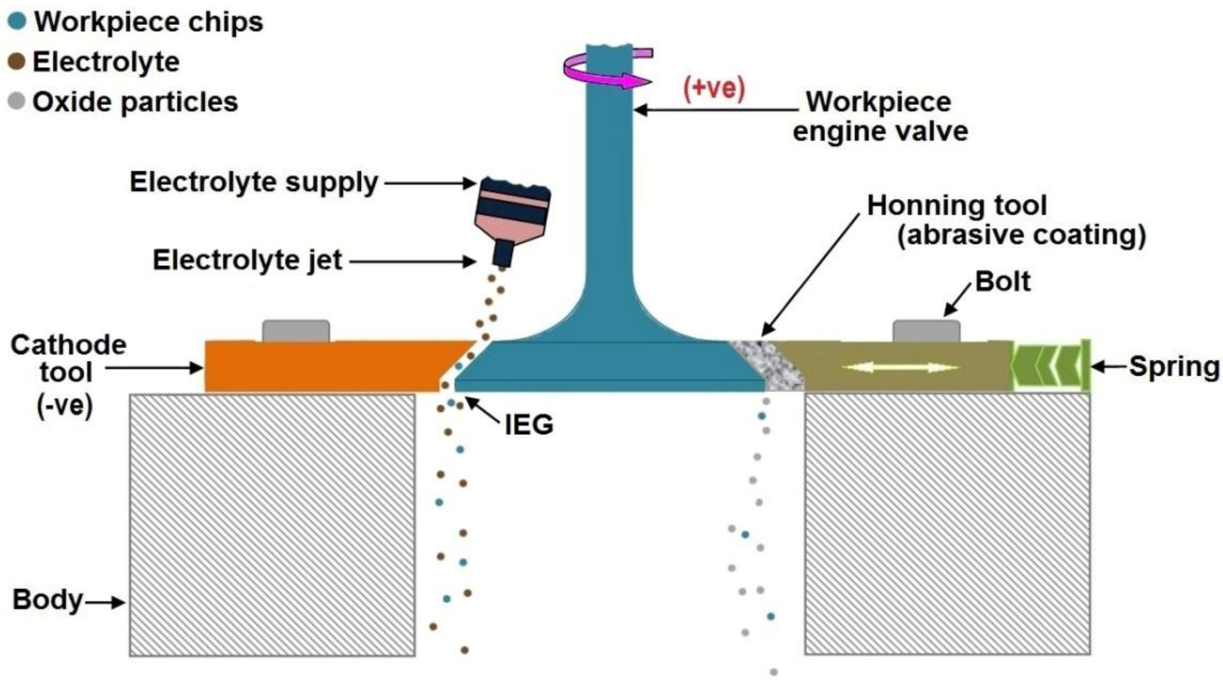


Fig. 5 Proposed process principle of ECH of engine valves

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