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TO FINISH TI-6AL-4V ALLOY BY CHEMO ASSISTED MAGNETIC ABRASIVE FLOW MACHINING

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ABSTRACT: *This study deals with a new approach to understand the finishing of Ti-6Al-4V alloy by chemical assisted magnetic abrasive finishing (CMAF) process. In the present work a CMAF setup is design and developed. In this process, material is removed by chemical dissolution as well as magnetic abrasive action on workpiece without applying any cutting forces on cutting zone. The present study also develops optimization for CMAF process of Ti-6Al-4V alloy using Taguchi method. Various parameters such as rotational speed from 60 to 180 rpm, concentration of abrasive from 10 to 20 %wt, and working gap from 2 to 6 mm to be considered for analyzing the chemical assisted magnetic abrasive finishing (CMAF) performance criteria e.g. percentage of surface roughness. From the analysis of variance of results, it is conclude that rotational speed has probability value of 0.027, which means it is most significant parameters of CMAF. For lower Surface roughness, the optimum parameters for chemical assisted magnetic abrasive finishing (CMAF) are rotational speed i.e. 180 rpm, concentration of abrasive is 15 %wt, and working gap is 4mm.*

I. INTRODUCTION

Biomaterials are defined as materials of natural or artificial origin that are used to direct, appendage, replace or support the functions of damaged and/or diseased parts of biological system. There are lots of materials used in the bio- medicine for a wide range of applications ranging from whole replacement of hard or soft tissues (like bone plates, total joint replacement, dental implants, pins, intra-ocular lenses, etc.), augment diagnostic or supportive devices (such as pacemakers, catheters, heart valves, etc.). Ti-6Al-4V is now being used as common material for bone implants because of its low density, excellent biocompatibility, high strength-to-weight ratio, corrosion resistance and good fatigue strength etc.

As technologies in modern industries advance, the machining processes involved are required to be more precise and efficient to obtain a quality product whilst maintaining high productivity. Life and functionality of a product is directly influenced by its surface finish.Precision and Ultra finishing process represents a critical and expensive phase of the overall production process. Manufacturing of precision parts consists a stage of final finishing operation.It is mostly uncontrollable, labour intensive and frequently involves a reasonable part of the total manufacturing cost. The functional properties such as wear resistance and power loss due to friction are influenced by surface roughness of the matching parts.

Abrasive flow machining can be thought of a process generating a self- forming tool that precisely removes workpiece material and finishes the surface at those areas restricting to the medium flow. AFM method is used for precision deburring, edge, contouring, and surface finishing. It is capable of finishing areas which are difficult to reach by flowing abrasive mixed with polymer of special theological properties. In this process tooling plays a very important role in finishing of material, therefore design of tooling should be done carefully.Magnetic Abrasive Finishing (MAF)is used to produce efficiently good surface quality on flat surfaces as well as internal and external surface of tube type workpieces. In magnetic abrasive finishing the cutting force can be controlled by the input current. Magnetic abrasive finishing has been able to give good surface and edge finishing by means of a magnetic abrasive brush formed in a magnetic field. Chemical mechanical polishing (CMP) is a process of finishing surfaces with the combination of chemical and mechanical forces. It is a hybrid of chemical etching and free abrasive polishing. In CMP abrasive and corrosive chemical slurry is used in conjunction with a polishing pad. Slurry is applied to the work piece surface, so that a softer oxide layer can be formed over the surface. Being softer, this oxide layer is much easier to be removed as compared to the parent material. Then the polishing pad is rotated with different axes of rotation to remove material and even out any irregular topography.

Limitation of above finishing processes are (a) Due to their high density, abrasive particle get sediment, (b) Variation in magnetic field during finishing operation happens, due to the presence of chips and non-uniformly distributed abrasive particle. (c) For finishing thick work pieces these processes cannot be applied, because of the high thickness of workpiece the magnetic field becomes quite low in finishing region compared to top surface where it is applied.Both MAF and CMP have several advantages due to which they are widely used by the industries. But they also have the limitation of low efficiency and low MRR, specially when applied to hard materials. A recent trend in precision surface finishing is to combine several processes together to obtain surface of superior quality. Therefore, a need is felt by industries to develop a combined finishing process, which produces an improved surface quality with greater efficiency. In the present work, a new process is developed by combining CMP and MAF, and is termed as Chemo Assisted Magnetic Abrasive Finishing (CMAF).

Ming Jiang et al. (1998) conducted experiments on Chemo-mechanical polishing (CMP) using various abrasives (boron carbide, silicon carbide, aluminium oxide, chromium oxide, zirconium oxide, silicon oxide, cerium oxide, iron oxide, yttrium oxide, copper oxide and molybdenum oxide. They investigate their relative effectiveness in the finishing of uniaxially pressed bearing balls by magnetic float polishing technique. CMP depends both on the chemical and on the mechanical effectiveness of the abrasive and the environment with respect to the workmaterial. Among the abrasives investigated for CMP of bearing balls, chromium oxide and zirconium oxide were found to he most effective abrasive.

Debin Wang et al. (2004) study discusses the finishing characteristics of a magnetic field assisted mechanochemical polishing process using Cr_2O_3 abrasive mixed with magnetic particles in the case of wet finishing using distilled water, which was proposed for internal finishing of Si_3N_4 fine ceramic tubes. It was clarified that a highly accurate finishing can be achieved more efficiently in the case of wet finishing using distilled water compared with dry finishing. Moreover, those conditions necessary to achieve high efficiency finishing are discussed.

K.B. Judal, and Vinod Yadava (2013) present research is to simulate cylindrical electro-chemical magnetic abrasive machining (C-EMAM) process for magnetic stainless steel (AISI-420). C-EMAM is a new hybrid machining process used for high efficiency finishing of cylindrical jobs made of advanced engineering materials. The material is removed from the workpiece surface due to simultaneous effect of abrasion and elec-trochemical dissolution. Finally a surface roughness model is developed by considering total volume of material removed with the assumption of triangular surface profile.

NiteshSihag et al. (2015) developed a new process which uses combination of chemical oxidation and magnetic field assisted abrasion (magnetic abrasive finishing) for faster processing. To establish the process experiments have been conducted on tungsten work piece and the effects of various process parameters like percentage weight of abrasive, oxidizing agent concentration, rotational speed of magnet and working gap on process response namely percentage change in average surface roughness value (ΔRa) was recorded. The experiments were planned using Taguchi L9 orthogonal array. Experimental data was analyzed using analysis of variance to understand contribution of various process factors on process response.

The objective of present work is to analyze the effect of process parameters (percentage weight of abrasive, oxidizing agent concentration, and working gap) on process response (percentage change in surface roughness). To obtain optimized machining parameters of CMAF.

II. EXPERIMENTAL WORK

The experiments are performed on Ti-6Al-4V alloy by using chemical assisted magnetic finishing. Various input process parameters varied during the experimentations i.e. rotational speed of magnetic, concentration of magnetic abrasive and gap between two magnetic.

A unique Chemo Assisted Magnetic Abrasive Finishing Setup (CMAF) set-up has been developed through complete design and fabrication. CMAF is a non-contact metal removal process used for finishing of hard materials. In this process, material is removed by chemical dissolution as well as magnetic abrasiveaction on workpiece without applying any cutting forces on cutting zone. Figure1 shows machining of Ti-6Al-4V alloy on developed CMAF setup. The set up consisted of two permanent magnetic disks and workpiece holding fixtures, which were designed and fabricated as required in the present set up. An aluminium disk having four blind holed was taken and to fabricate permanent magnetic tool, a set of NdBFe magnetic disks (Ø120mm X 25 mm thick) were inserted in each hole making arrangement of alternative north and south pole.To provide the required rotational motion to upper magnet,it was held in rotating disk motor. The lower magnetis fixed on the machine table opposite to the upper magneticdisk. Two magnetic disks were placed opposite to each otherand work piece was placed between them. To allow the chemical reaction over the work piece surface,it was kept in contact with the chemical agent before startingthe experiments. In the present work nitric acid was selected as chemical agent. Then work piece washeld with help of specially designed fixtures. A mixture offerromagnetic and abrasive particles is filled in the gapbetween workpiece and upper magnet.When mixed abrasive is supplied into the tank, the magnetic particles are accumulated at the finishing area by the magnetic field, which mixes Al_2O_3 abrasives along the flow of magnetic flux, and pressing Al_2O_3 abrasives against the surface of the workpiece by magnetic force. A relative movement is caused between the mixed abrasive and the finishing surface when the magnetic pole is rotated at high-speed.

Fig 1: Machining of Ti-6Al-4V alloy on Developed CMAF Setup

A chemical reaction occurs between the finishing surface of Ti-6Al-4V alloy and the Al_2O_3 abrasive. The mixed abrasives at a high-speed rotation mechanically remove the reaction product, and the surface of the Ti-6Al-4V alloy is smoothly finish by chemical as well as magnetic abrasive action.To analyze the performance of CMAF three process parameters were selected namely rotational speed of magnetic, concentration of magnetic abrasive and gap between two magnetic. In addition, these experiments helped in deciding the finishing time for each experiment as 20 minutes. Detail of process factors is given in table 1.

Table 1: $L_9(3^3)$ orthogonal array of CMAF process

Experiment No.	Parameters and their Levels		
	rotational speed of magnetic	concentration of magnetic abrasive	Working gap
1	60	10	2
2	60	15	4
3	60	20	6
4	120	10	4
5	120	15	6
6	120	20	2
7	180	10	6
8	180	15	2
9	180	20	4

In the present work important response variables viz. surface roughness are being measured and studied. Every time the material is removed from the work piece due to chemical reaction by etchant, at the same time material is finished by magnetic abrasive action. Theinitial surface roughness of the samples are 0.35 microns. The surface roughness wasmeasured using Talysurfprofilometer with a sampling lengthof 2mm.Process response, i.e. percentage change in surfaceroughness is calculated by the following formula.

% Ra = (Intial Ra – Final Ra) / Intial Ra x 100

III. RESULTS AND DISCUSSION

The experiments are designed according to number of variables and responses to be measured for that variable. Based on the preliminary experiments, three important variables are identified i.e. rotational speed, concentration of abrasives and working gap on the surface roughness as shown in table 2.

Table 2: Ti-6Al-4v alloy finishing experimental conditions

Workpiece	Ti-6Al-4v alloy
Abrasives	Al_2O_3 1.5 g (120 μm in mean diameter)

Mixed Abrasive	Iron Particles: 1.5 g (510 µm in mean diameter)
Machining fluid	Nitric Acid
Pole	Nd-Fe-B permanent magnet
Constant Parameters	
Water	100 ml
Variable Parameters	
Rotational Speed	60,120 and 180 rpm
Concentration of Abrasives (%wt)	10,15 and 20
Working Gap	2,4 and 6mm

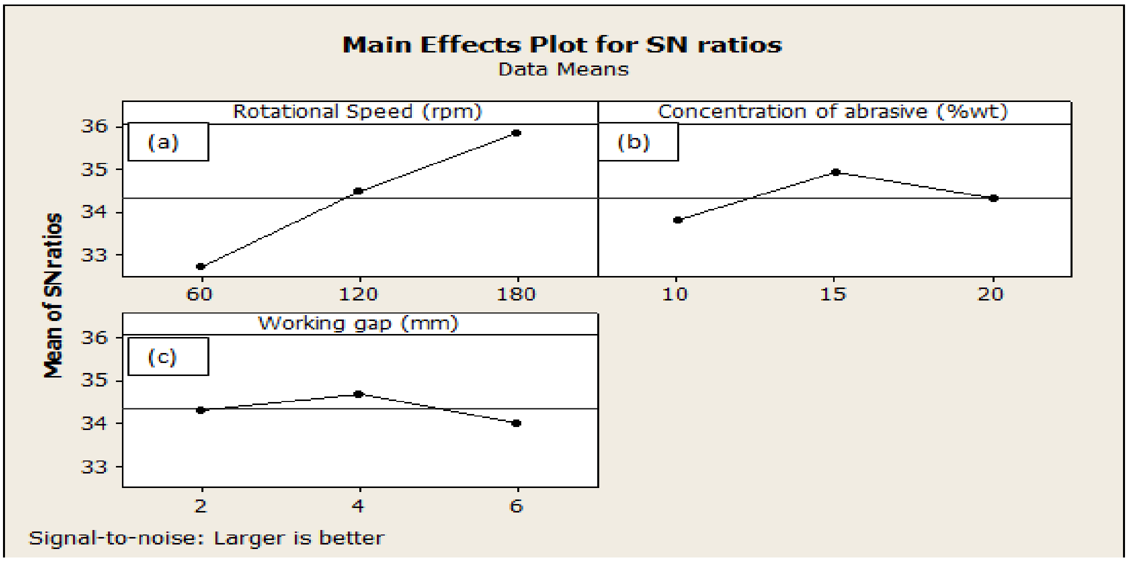

Fig 2: Mean of SN ratio of Surface Roughness

Figure 2 (a) shows the effect of Rotational speed on Mean of SN Ratios of surface roughness. Graph plotted by utilizing the surface roughness results obtained at variation of Rotational speed 60,120 and 180 rpm, Concentration of Abrasives (%wt)10,15 and 20, Working Gap 2,4 and 6mm.It is clear that there is increase in surface roughness with the increase of Rotational Speed.Figure 2 (b) shows the effect of Concentration of Abrasives (%wt) on Mean of SN Ratios of Surface Roughness. Graph plotted by utilizing the Surface Roughness results obtained at variation of Rotational speed 60,120 and 180 rpm, Concentration of Abrasives (%wt)10,15 and 20, Working Gap 2,4 and 6mm. It is clear that there is increase in Surface Roughness with the increase of Concentration of Abrasives (%wt) from level-1 to level-2 i.e.10 to 15gm and than decreases from level-2 to level-3 i.e. 15 to 20gm.Figure 2 (c) shows the effect of Working gap on Mean of SN Ratios of surface roughness. Graph plotted by utilizing the surface roughness results obtained at variation of Rotational speed 60,120 and 180 rpm, Concentration of Abrasives (%wt)10,15 and 20, Working Gap 2,4 and 6mm.It is clear that there is increase in surface roughness upto level-2 i.e. 4mm and than decreases upto level-3 i.e. 6mm with the increase of working gap.

General Linear Model: MEAN1 versus Rotational S, Concentratio, ...

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Factor                           Type   Levels  Values
Rotational Speed (rpm)           fixed       3  60, 120, 180
Concentration of abrasive (%wt)  fixed       3  10, 15, 20
Working gap (mm)                 fixed       3  2, 4, 6


Analysis of Variance for MEAN1, using Adjusted SS for Tests

Source                           DF  Seq SS  Adj SS  Adj MS      F      P
Rotational Speed (rpm)            2  526.21  526.21  263.10  35.80  0.027
Concentration of abrasive (%wt)   2   60.66   60.66   30.33   4.13  0.195
Working gap (mm)                  2   22.57   22.57   11.29   1.54  0.394
Error                             2   14.70   14.70    7.35
Total                             8  624.15


S = 2.71113   R-Sq = 97.64%   R-Sq(adj) = 90.58%
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Figure 3: Analysis of variance for mean of surface roughness

Figure 3 shows the analysis of variance (ANOVA) of CMAF parameters for optimizing the surface roughness. Probability value for Rotational speed was below 0.05 i.e. 0.027 which means it is significant parameters of CMAF. It can be observed that Rotational speed has the largest effect on the mean of means of Surface Roughness of CMAF. The Working gaphas the smallest effect on the mean of means of Surface Roughness of CMAF. Its means that Rotational speed is significant parameter which effect on the surface roughness during finishing by CMAF.

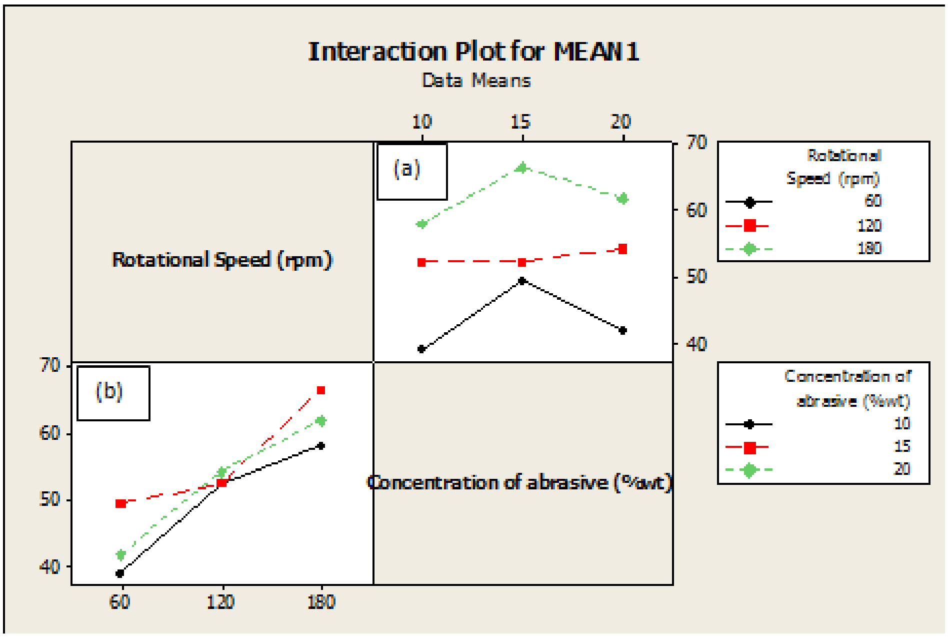

Fig 4: Interaction plot for rotational speed and concentration of abrasives for surface roughness

The Figure 4 shows interaction effect of Rotational Speed and Concentration of Abrasives on Surface Roughness. It is clear that at level 1 of Rotational speed i.e. 60 rpm; the Surface Roughness increases by increasing concentration of abrasives from level 1 to level 2 i.e. 10gm to 15gm. By further increasing the concentration of abrasives from level 2 to level 3 i.e. 15 to 20gm the Surface Roughness decreases.At level 2 of Rotational speed i.e. 120 rpm; the Surface Roughness is almost constant by increasing concentration of abrasives from level 1 to level 2 i.e. 10 to 15gm. By further increasing the concentration of abrasives from level 2 to level 3 i.e. 15 to 20gm the Surface Roughness increases.At level 3 Rotational speed i.e. 180 rpm; the Surface Roughness increases by increasing concentration of abrasives from level 1 to level 2 i.e. 10 to 15gm. By further increasing the concentration of abrasives from level 2 to level 3 i.e. 15 to 20gm the Surface Roughness decrease.

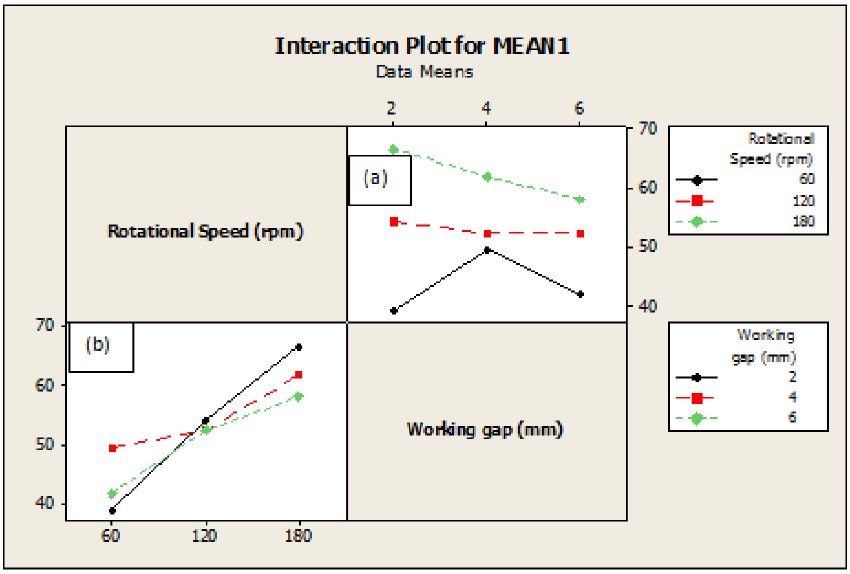

Fig 5: Interaction plot for Rotational speed and Working gap for Surface Roughness

The Figure 5 shows interaction effect of Rotational Speed and Working gap on Surface Roughness. It is clear that at level 1 of Rotational speed i.e. 60 rpm; the Surface Roughness increases by increasing Working gap from level 1 to level 2 i.e.

2 to 4mm. By further increasing the Working gap from level 2 to level 3 i.e. 4 to 6mm the Surface Roughness decreases. At level 2 of Rotational speed i.e. 120 rpm; the Surface Roughness decreases slightly by increasing Working gap from level 1 to level 2 i.e. 2 to 4mm. By further increasing the Working gap from level 2 to level 3 i.e. 4 to 6mm the Surface Roughness remains constant. At level 3 Rotational speed i.e. 180 rpm; the Surface Roughness decreases by increasing Working gap from level 1 to level 2 i.e. 2 to 4mm. By further increasing the Working gap from level 2 to level 3 i.e. 4 to 6mm the Surface Roughness decrease.

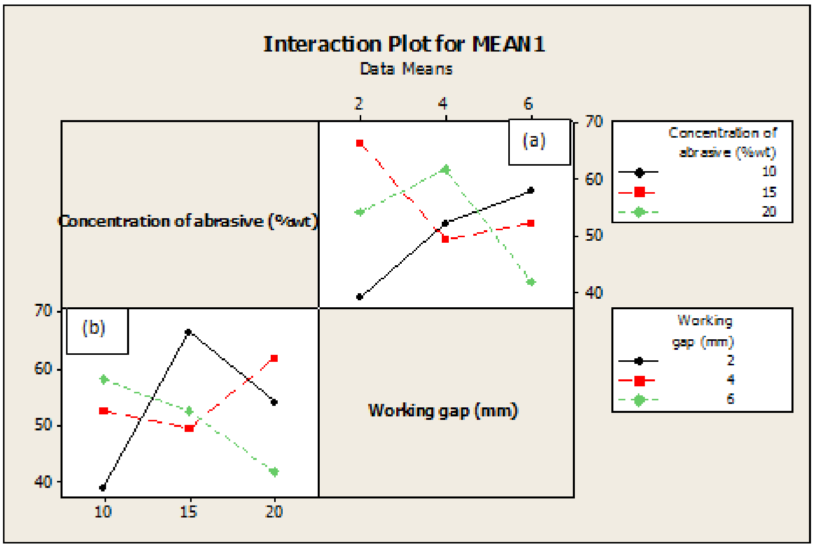

Fig 6: Interaction plot for Concentration of abrasives and Working gap for Surface Roughness

The Figure 6 shows interaction effect of Concentration of Abrasives and Working gap on Surface Roughness. It is clear that at level 1 of Concentration of abrasives i.e. 10gm; the Surface Roughness increases by increasing Working gap from level 1 to level 2 i.e. 2 to 4mm. By further increasing the Working gap from level 2 to level 3 i.e. 4 to 6mm the Surface Roughness increases.At level 2 of Concentration of abrasives i.e. 15gm; the Surface Roughness decreases by increasing Working gap from level 1 to level 2 i.e. 2 to 4mm. By further increasing the Working gap from level 2 to level 3 i.e. 4 to 6mm the Surface Roughness increases.At level 3 Concentration of abrasives i.e. 20gm; the Surface Roughness increases by increasing Working gap from level 1 to level 2 i.e. 2 to 4mm. By further increasing the Working gap from level 2 to level 3 i.e. 4 to 6mm the Surface Roughness decrease.

IV. CONCLUSIONS AND SCOPE OF FUTURE

In present work, the experimental study finishing of Ti-6Al-4v alloy by CMAF. A total of 9 experiments were conducted to identify the best possible finishing characteristics to minimize the SR. The conclusions were as follows.

- The chemical assisted magnetic abrasive finishing (CMAF) setup is successfully developed for finishing of hard material i.e. Ti-6Al-4v alloy.
- The lowest surface roughness is noted i.e. 0.11 Ra, rotational speed i.e. 180 rpm, concentration of abrasive is 15 %wt, and working gap is 2mm.
- The percentage of surface roughness is increase by increasing rotational speed due to along the flow of magnetic flux, and pressing Al_2O_3 abrasives against the surface of the workpiece (Ti-6Al-4V alloy) by magnetic force
- The percentage of surface roughness is decrease by increasing the concentration of abrasive at certain limit due to more energy is waste to rotate the magnetic particles.
- The percentage of surface roughness is decrease after 4 mm gap; because more gap means loss of magnetic field.
- From the analysis of variance of results, it is conclude that rotational speed has probability value of 0.027, which means it is most significant parameters of CMAF.
- For lower Surface roughness, the optimum parameters for chemical assisted magnetic abrasive finishing (CMAF) are rotational speed i.e. 180 rpm, concentration of abrasive is 15 %wt, and working gap is 4mm.

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