International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 04 - Issue 03 || March 2019 || PP. 20-27

Experimental Investigation of Abrasive Flow Machining Process Alongwith Fuzzy Logic and Grey Relation Analysis

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Abstract: The internal surfaces of the workpiece are finished to nano-scale using the impact force provided by abrasive laden media. This media is extruded past the surface and is provided required pressure by piston cylinder arrangement. In this paper the experimental values of material removal and surface roughness are compared with the values obtained by different optimization software, i.e. grey relational analysis, minitab fuzzy logic optimization. The different input parameters taken were rotational speed, extrusion pressure, number of cycles, supply voltage, abrasive mesh size, whereas output response i.e. material removal and surface roughness were optimized using the minitab software. It was found that the values were in close proximity to each other.

Keywords: minitab, media, material removal, surface roughness

1. Introduction and Literature Review:

In abrasive flow machining the media flow pressure is used to finish the internal surface profiles. The efficiency of the process is increased by addition of external forces like magnetic field, rotational attachments, etc. that results in enhanced material removal. The development and usage of different polymer media results in different output results in terms of roughness integrity of the work surface. The rectangular microgroove of Cu and SUS 304 materials were abrasive flow finished using a low pressure abrasive flow polishing (LAFP) process and surface roughness of Ra 4.8 and 12.7 nm was obtained respectively. In addition, turbulence model of the developed setup, CFD process, two phase flow and shear force simulation was done along with particle trajectory and the resembled the experimental results. [1]. Figure 1 shows abrasive flow machine set up. The surface roughness value of IN625 component was reduced by 45% and the semi-welded particles from the surface were removed. The Ra improved from 17.4 µm to 14.2 µm and the polishing time was reduced from 3 to 1 hour in this hybrid process as compared to conventional individual process. Hence the problem of pollution in engine parts and flow of fluid compromise due to bad texture were overcome using this technique. In addition, additive manufacturing like selective laser melting and electron beam melting were applied in order to get fine surface quality [2] In the paper, a model of constrained passage media flow was prepared using Discrete Phase Model and Computational Fluid Dynamics. Out of the four types, i.e. golf ball, chevron, triangle and constrained plate, the triangle type resulted in maximum material removal and best surface finish due to the high dynamic pressure and increasing number of collisions of active abrasive particles on the work surface [3] In this paper, Taguchi method of philosophy was applied to optimize the results and it was found that 26% improvement in surface roughness occurred using the combination of input parameters i.e. pressure 15 bar, abrasive concentration 10 gm and number of cycles 6 [4] The material removal was increased by increase in wall shear rate, and rise in volume fraction of abrasive particles. A two-dimensional model was designed and forces were calculated at different volume fractions using computational fluid dynamics simulation method [5].

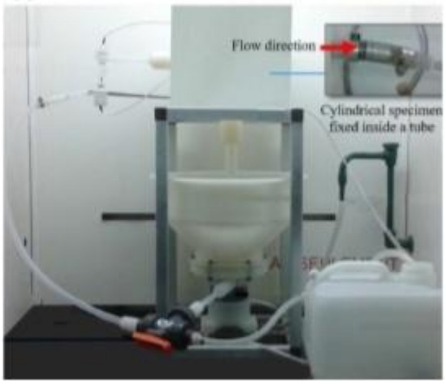

Fig.1. Chemical abrasive polishing setup

The surface roughness value obtained from selective laser melting (SLM) process was 10 µm. This value was reduced using abrasive flow machining process on maraging steel 300 used in mold industry. About 2 µm roughness value was obtained depending on the type of media used, i.e. abrasive concentration and viscosity. Apart from surface roughness, residual stresses were also measured. On the non-heat treated SLM surfaces, the increase in compressive residual stresses perpendicular to media flow was found to be 360 MPa and on heat treated surfaces, it was found to be 600 MPa parallel to fluid flow [6]. In this paper, hybrid abrasive flow machining models developed by various researchers and scientists were studied in detail and their performance were compared. Different polymer media used were studied in detail [7].

The styrene butadiene rubber (SBR) media was developed and used to finish different materials in AFF process (Sankar et al 2009) [8]. The force on abrasive grain was predicted and the depth of indentation was calculated to check the material deformation (Gorona et al 2006) [9]. The different parameter like workpiece modulus of elasticity, yield strength, load, grain size had effect on the amount of material removal (Yang and Kao 209) [10]. In the paper, abrasive electrochemical machining (AECM), abrasive electrochemical grinding (AECG), electrochemical honing and abrasive electrical discharge machining (AEDM) were studies (Kozaka et al 2001) [11]. The optimum surface roughness was obtained when the extrusion pressure was kept at 40 bar, while uniform roughness at 70 bar (Swata et al 2014) [12]. The different type of mechanical advanced machining process were discussed (Jain and Jain 2001) [13]. In AFM process the viscoelastic carrier affected the mixing that reduced the modulus of media by 10-86 % (Kar et al 2012) [14]. The non-Newtonian fluid is used as polymer media in AFM process that were affected by strain and temperature, the velocity of A-Silicone is 20 times lesser than P-Silicone (Wang et al 2007) [15]. The temperature change of workpiece was predicted by help of specific energy in AFM process i.e. 10-110 J/mm^3 (Jain and Jain 2001) [16]. The surface integrity obtained by EDM process was improved by the application of AFM process (Kenda et al 2011) [17]. The sustainability of manufacturing process was discussed in 3 sections, Type A, B, C, were denoted to explain the energy, material efficiency and materials or components used (Aurich et al 2013) [18]. The surface roughness was improved with the help of ball-shaped pole of magnetic brush that was flexible in nature (Lin et al 2007) [19]. Computational Fluid Dynamics (CFD) technique was used to study the flow of media in AFM process that concluded that shear rate affected media viscosity, and the working gap had the significant effect on the surface finish (Wang et al 2009) [20]. The simulation was done to reduce the cost and effort in process layout so that AFM process could be run smoothly (Uhlmann et al 2013) [21]. The twin flapper nozzle valve was used in AFM model to obtain high accuracy (Yang and Sha 2014) [22]. The section geometry, air supply in the way of workpiece in fluidized bed had been highlighted to study the process effect (Barletta 2009) [23]. The effect of hybrid abrasive flow machine that utilizes magnetic field in addition to extrusion force of media cylinder is clearly explained in table 1. It includes the contribution of various scientists in this field.

2. Abrasive Flow Machining Results in Terms of Material Removal and Roughness:

The output results are tabulated in table 1 to 5. The output results corresponds to different input parameters, i.e. extrusion pressure EP, rotational speed RS, number of cycles NC, workpiece WT, abrasive AT, ECM voltage EV, magnetic voltage MV.

Table 1: MS, EP and RS

MS, EP and RS					
Ra	Normalised	MR	Normalised	MPCI	Rank
8.37	0.07	3.7	0.00	0.0655	9
6.8	0.00	6.5	0.45	0.25	8
23.1	0.74	6.9	0.52	0.5443	2
11.33	0.21	8.1	0.71	0.4157	6
12.45	0.26	9.9	1.00	0.5557	1
16.1	0.42	6.5	0.45	0.45	4
28.89	1.00	4.7	0.16	0.4958	3
15.09	0.38	5	0.21	0.3181	7
22.19	0.70	5.5	0.29	0.445	5

Table 2: EP (1), NC (2) and WT (3)

EP (1), NC (2) and WT (3)					
Ra	Normalised	MR	Normalised	MPCI	Rank
23.4	0.70	4.1	0.28	0.4403	6
16.9	0.41	4.13	0.29	0.3729	7
29.9	1.00	3.16	0.14	0.4819	4
17.01	0.41	5.14	0.44	0.45	5
13.69	0.26	8.95	1.00	0.5557	2
12.98	0.23	7.93	0.85	0.4955	3
24.91	0.77	6.01	0.57	0.5613	1
7.9	0.00	5.19	0.44	0.25	8
9.99	0.10	2.19	0.00	0.06718	9

Table 3: AT (1), AM(2) and AR (3)

AT (1), AM(2) and AR (3)					
Ra	Normalised	MR	Normalised	MPCI	Rank
23.01	0.716	4.1	0.28	0.4482	6
15.4	0.355	4.13	0.29	0.3496	7
29	1	3.16	0.14	0.4819	3
17.8	0.469	5.14	0.44	0.45	5
13.33	0.257	8.95	1.00	0.554	1
12.1	0.199	7.93	0.85	0.479	4
24	0.763	6.01	0.57	0.5	2
7.9	0	5.19	0.44	0.25	8
9.9	0.094	2.19	0.00	0.067	9

Table 4: EV (1), ER (2) and ES (2)

EV (1), ER (2) and ES (2)					
Ra	Normalised	MR	Normalised	MPCI	Rank
10.37	0.068	4.1	0.28	0.1989	9
8.8	0	4.13	0.29	0.2037	8
25.7	0.7322	3.16	0.14	0.3779	5
14.43	0.244	5.14	0.44	0.3466	6
15.57	0.2933	8.95	1.00	0.5748	3
19.02	0.443	7.93	0.85	0.6109	2
31.88	1	6.01	0.57	0.65	1
18.09	0.4025	5.19	0.44	0.45	4
25.2	0.7106	2.19	0.00	0.3274	7

Table 5: MT (1), MV (2) and ET(3)

MT (1), MV (2) and ET(3)					
Ra	Normalised	MR	Normalised	MPCI	Rank
9.11	0.10	2.2	0.00	0.06718	9
7.01	0.00	5.2	0.51	0.25	8
24.17	0.78	6	0.65	0.6135	1

12	0.23	7.04	0.82	0.4756	6
13.47	0.29	8.09	1.00	0.5729	2
17.9	0.49	5.99	0.64	0.4819	5
29.1	1.00	3.79	0.27	0.5613	3
16.9	0.45	4.04	0.31	0.385	7
23.2	0.73	4.9	0.46	0.5387	4

2.1. Fuzzy logic optimization applied to abrasive flow machining results:

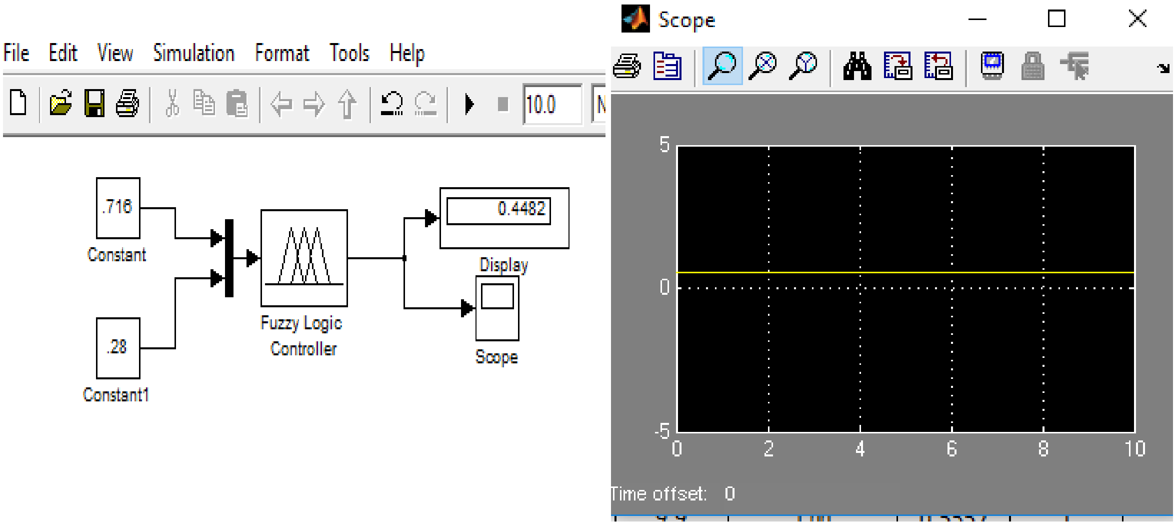

Fig. 1 Fuzzy logic opereators

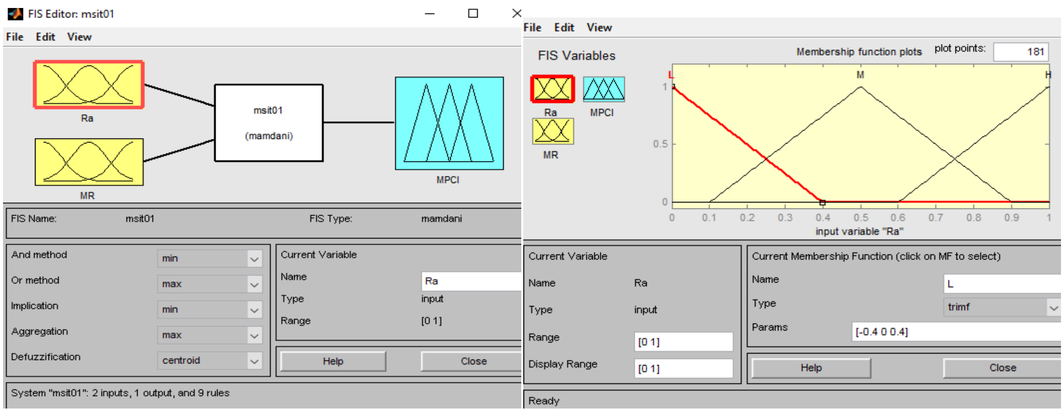

Fig.2 Fuzzy logic operator FIS variables

2.2. GRC and PCA applied to output results:
The grey relation and PCA results are shown in table 6 to 10.

Table 6: MV, EV and RS

MV, EV and RS							
Ra	Normalised	Deviation	GRC	MR	Normalised	Deviation	GRC
8.37	0.07	0.93	0.347	3.7	0.00	1.00	0.333
6.8	0.00	1.00	0.333	6.5	0.45	0.55	0.476
23.1	0.74	0.26	0.658	6.9	0.52	0.48	0.510
11.33	0.21	0.79	0.388	8.1	0.71	0.29	0.633
12.45	0.26	0.74	0.403	9.9	1.00	0.00	1.000
16.1	0.42	0.58	0.463	6.5	0.45	0.55	0.476

28.89	1.00	0.00	1.000	4.7	0.16	0.84	0.373
15.09	0.38	0.62	0.446	5	0.21	0.79	0.388
22.19	0.70	0.30	0.625	5.5	0.29	0.71	0.413

Table 7: MV, EV and RS

MV, EV and RS							
Ra	Normalised	Deviation	GRC	MR	Normalised	Deviation	GRC
23.4	0.70	0.30	0.625	4.1	0.28	0.72	0.409
16.9	0.41	0.59	0.458	4.13	0.29	0.71	0.413
29.9	1.00	0.00	1	3.16	0.14	0.86	0.367
17.01	0.41	0.59	0.458	5.14	0.44	0.56	0.471
13.69	0.26	0.74	0.403	8.95	1.00	0.00	1
12.98	0.23	0.77	0.393	7.93	0.85	0.15	0.769
24.91	0.77	0.23	0.684	6.01	0.57	0.43	0.537
7.9	0.00	1.00	0.333	5.19	0.44	0.56	0.471
9.99	0.10	0.90	0.357	2.19	0.00	1.00	0.333

Table 8: MV, EV and RS

MV, EV and RS							
Ra	Normalised	Deviation	GRC	MR	Normalised	Deviation	GRC
23.01	0.72	0.28	0.641	4.1	0.28	0.72	0.409
15.4	0.36	0.64	0.438	4.13	0.29	0.71	0.413
29	1	0	1	3.16	0.14	0.86	0.367
17.8	0.47	0.53	0.485	5.14	0.44	0.56	0.471
13.33	0.26	0.74	0.403	8.95	1.00	0.00	1
12.1	0.19	0.81	0.381	7.93	0.85	0.15	0.769
24	0.76	0.34	0.595	6.01	0.57	0.43	0.537
7.9	0	1	0.333	5.19	0.44	0.56	0.471
9.9	0.09	0.91	0.354	2.19	0.00	1.00	0.333

Table 9: MV, EV and RS

MV, EV and RS							
Ra	Normalised	Deviation	GRC	MR	Normalised	Deviation	GRC
10.37	0.06	0.94	0.94	4.1	0.28	0.72	0.409
8.8	0	1	1	4.13	0.29	0.71	0.413
25.7	0.73	0.27	0.27	3.16	0.14	0.86	0.367
14.43	0.24	0.76	0.76	5.14	0.44	0.56	0.471
15.57	0.29	0.71	0.71	8.95	1.00	0.00	1
19.02	0.44	0.56	0.56	7.93	0.85	0.15	0.769
31.88	1	0	0	6.01	0.57	0.43	0.537
18.09	0.40	0.60	0.6	5.19	0.44	0.56	0.471
25.2	0.71	0.29	0.29	2.19	0.00	1.00	0.333

Table 10: MV, EV and RS

MV, EV and RS							
Ra	Normalised	Deviation	GRC	MR	Normalised	Deviation	GRC
9.11	0.10	0.90	0.357	2.2	0.00	1.00	0.333
7.01	0.00	1.00	0.333	5.2	0.51	0.49	0.505
24.17	0.78	0.32	0.609	6	0.65	0.35	0.588
12	0.23	0.77	0.393	7.04	0.82	0.18	0.735
13.47	0.29	0.71	0.413	8.09	1.00	0.00	1
17.9	0.49	0.51	0.495	5.99	0.64	0.36	0.581
29.1	1.00	0.00	1	3.79	0.27	0.73	0.406
16.9	0.45	0.55	0.476	4.04	0.31	0.69	0.420
23.2	0.73	0.27	0.649	4.9	0.46	0.54	0.480

2.3. Taguchi, descriptive statistics and time series analysis:

Main Effects Plot for Means, main Effects Plot for SN ratios, factor Analysis: MV, EV, RS, principal Component Factor Analysis of the Correlation Matrix and unrotated Factor Loadings and Communalities are shown in table 11 and 12 and in figure 3 and 4.

Table 11: Taguchi results

Variable	Factor1	Factor2	Factor3	Communality
MV	-1.000	0.000	0.000	1.000
EV	0.000	-1.000	0.000	1.000
RS	0.000	0.000	-1.000	1.000
Variance	1.0000	1.0000	1.0000	3.0000
% Var	0.333	0.333	0.333	1.000

The chi-square approximation may not be accurate when some sample sizes are less than 5.
Mood's Median Test: Ra versus MV.

Table 12: Descriptive Statistics

MV	Median	N <= Overall Median	N > Overall Median	Q3 – Q1	95% Median CI
50	8.37	2	1	16.30	(6.8, 23.1)
125	12.45	2	1	4.77	(11.33, 16.1)
200	22.19	1	2	13.80	(15.09, 28.89)
Overall	15.09				

Levels with < 6 observations have confidence < 95.0%

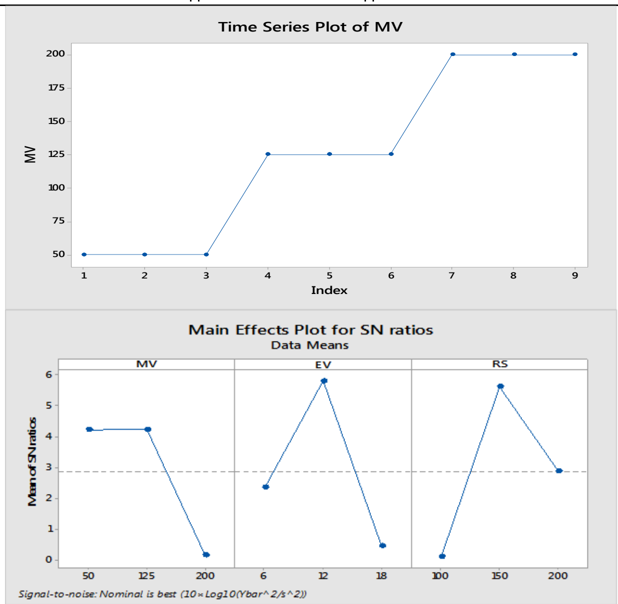

Table 3: Time series plot of MV and main effects

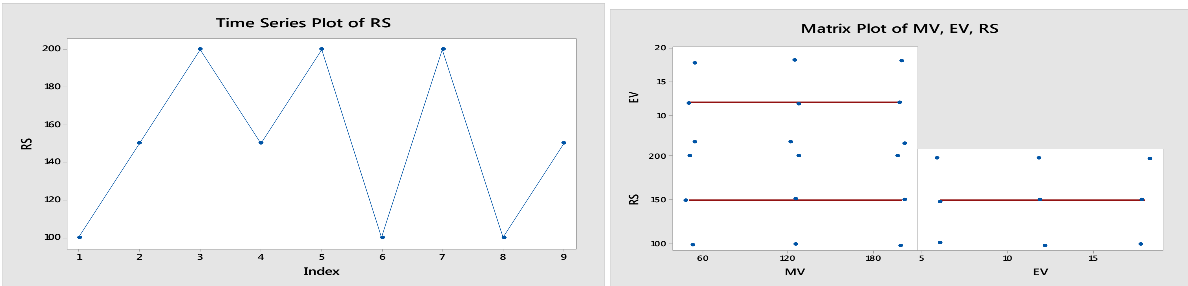

Table 4: Time series and matrix plot

3. Conclusions:

The results of experimentation were successfully validated and compared with different optimization techniques i.e. Taguchi L9 OA, RSM, Minitab fuzzy logic and grey relational analysis in order to enhance material removal and obtain better surface roughness. The experimental values and mathematical modeling values were in close agreement with each other. The development and fabrication of hybrid magneto electro-chemo abrasive flow machining fixture was done successfully. This setup was run and higher material removal was obtained as compared to conventional AFM setup.

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