Investigation and Optimization of Process Parameters in Electrochemical Aid Abrasive Flow Machining

Ravi Gupta, Balinder Chahal

Abstract

AFM is effective advance machining process that is widely used where finishing is difficult to access, such as radius polish, removal recast layer and complex internal passage by using the semi-solid media flow into the work piece. The media consists of a type of polymeric carrier and abrasive particles that are Sic, Al_2O_3, diamond, etc. This process is generally labor intensive, low material removal rate process and time consuming process. But now a days, Hybrid process have been developed to improve the surface finish and material removal rate of abrasive flow machine. The hybrid process of electrochemical machining and abrasive flow machining is called ECA^2FM. In ECA^2FM the electrolytic salts-abrasive laden media passes through cathode rod, the work-piece anode, connected with the DC power source. In this experimental investigation, process parameters, such as voltage, molal concentration, number of cycle and rotational diameter of rod were studied at different levels for material removal. It result in more machining as compare to AFM. In the present work, the more effective parameter is intensified and effects of the parameter on the material removal is observed by using Taguchi technique.

Keywords

Electrochemical Assisted Abrasive flow machining (ECA2FM), Taguchi Technique, ANOVA

1. **Introduction**:

The machining process reduced the human efforts and increased the production rate with accurate dimension and good surface finish. Different type of the conventional process such as turning, facing, milling, drilling are used generally for machining. But the conventional finishing processes of this category has various limitations like complex shape, miniature size and three dimensional parts(3D) parts cannot be finished economically and rapidly. To overcome this limitation, many non-conventional machining process has been developed, which shows significant improvement over Conventional method.

Abrasive flow machining process is one of non-conventional process developed for effective machining. It also known as extrude honing process used in metalworking. This process is used to finish the interior surfaces of cast metals and produce controlled radii by using semi-solid media flow into the work-piece. The process of abrasive flow machining produces a smooth, polished finish using a pressurized media. The media constituents were gel, polymer and abrasive particles of aluminum oxide (Al_2O_3). Abrasive particles like silicon carbide and diamond powder also used in abrasive media. Abrasive flow machining equipment is made in one way and two way AFM. In a one way AFM, the abrasive media is forced through the project at an entry point and then exits on the other side, leaving a polished interior to mark its passage. For more aggressive polishing, the two way abrasive flow machining system might be employed. In two way AFM, the abrasive media flow is controlled by two hydraulic cylinders. The piston inside these cylinders provide alternate motion to the media through the workpiece. It delivers a smoother, highly polished end result in much less time as compared to one way AFM. The components of AFM process are the machine, tooling and abrasive medium. AFM suffers from the limitation of low material removal rate. According to recent studies, abrasion rate in AFM can be enhanced by using hybrid machining such as

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electrochemical machining aid with abrasive flow machining (ECA^2FM).So keeping these points in mind, a research based upon experiments was carried out.

2. Electrochemical assisted abrasive flow finishing

The nylon fixture used in ECA2FM is provided with two copper electrode in which one acts as cathode connected with triangular rod, while the other acts as anode connected with work piece. The triangular cathode rod passes between the hollow work pieces to complete the circuit of electro chemical machining. The fixture was fixed between the two opposite hydraulic cylinder tightly with screws in order to the avoid leakage. The electrodes was connected to low voltage power source having range of 0-30V.The media is filled in the lower cylinder and the extrusion pressure on upper cylinder is applied which allows the media to pass through the restricted space between the cathode rod and the anodic work piece. When the media flows through the space between the cathode rod and the work piece, it results in material removal rate and efficiency is increased due to the additional electrolytic machining along mechanical machining due to acting action of the abrasive. Media used for ECA2FM consists of Al203 particle, silicon based polymer and hydrogen gel with Nacl salt. The abrasive to media ratio was taken as 1:1:1.The concentration of sodium chloride was varied at different level. In simple AFM process, only abrasive helps to remove material from work piece which results in less material removal. But in ECA2FM, material removal occurs by combination of AFM and ECM. It enhance the rate of material removal. When voltage applied, material was removed from workpiece due to action of ECM and abrasion action of AFM. The mechanism of material removal is shown in figure 3.The key parameters were voltage, no. of cycle, molal concentration and diameter of rod. Experiments were performed with simple AFM process and by making it hybrid as ECA2FM. The gun metal was used as work-piece material in experiments. The workpiece was given hollow cylindrical shape by drilling process followed by boring. The dimension was taken as 8 mm internal diameter, 12.6mm external diameter and 15mm length as shown in figure 2.The schematic diagram is shown in figure 4.

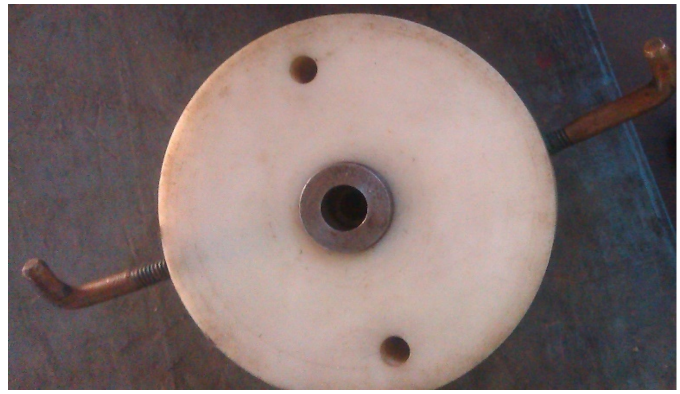

Figure 1: Nylon Fixture for ECA^2FM

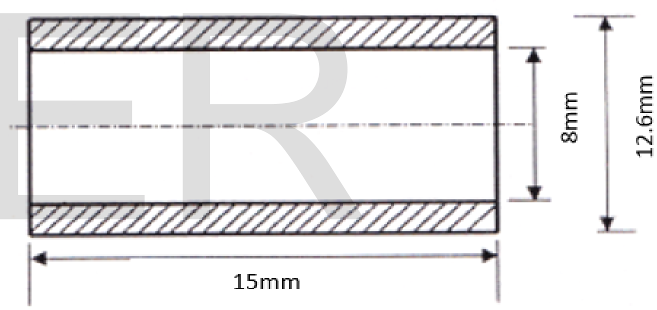

Figure 2: Work-Piece

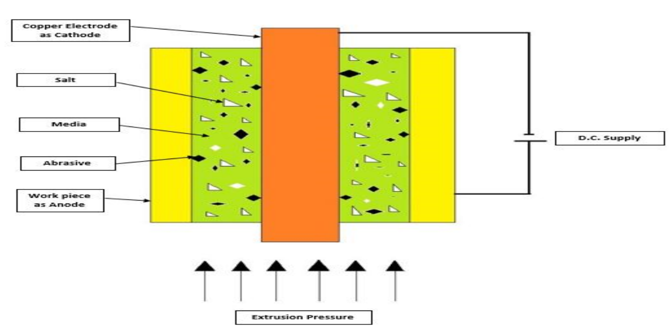

Figure 3: Mechanism of material removal

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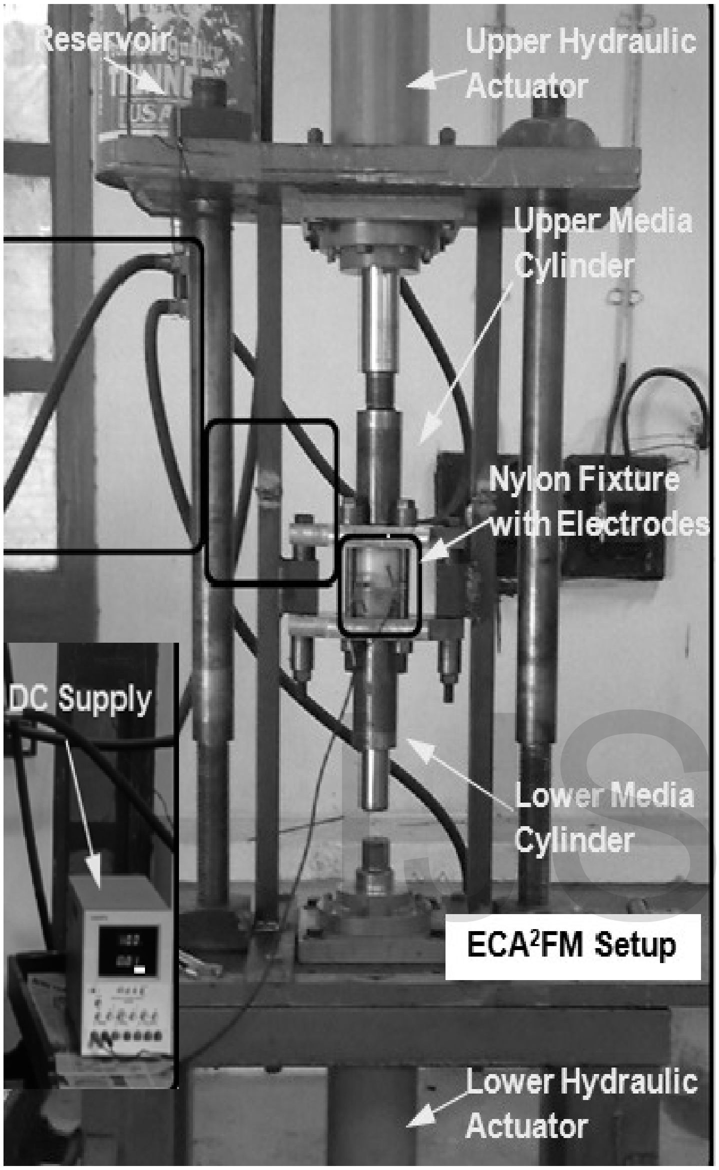

Figure 4: Schematic of ECA^{2}FM Process

3. Literature Survey

Many researchers presented their own theories on the abrasive flow machining such as Rhoades [1-3] study the basic principle of AFM process and identified its control parameters. He observed that its viscosity temporarily rise when the medium is suddenly forced through restrictive passage. AFM can be used in industrial applications such as automobile, medical, aerospace etc. [4]. Rajurkar [5] studied the effect of medium viscosity and extrusion pressure on metal removal rate and surface finish used the full factorial design for experimentation. Jain and Adsul [6] reported that initial surface roughness and hardness of the work piece are important parameters affecting the material removal rate in AFM. Loveless [7] studied on surface finish the effect of viscosity of media. They found that viscosity is the only parameter which significantly affects the surface finish. They found the relationship between initial surface finish and percentage improvement in surface finish is non-linear. Singh and Shan [8] applied a magnetic field around the work piece and observed that the presence of magnetic field significantly improves the surface finish and material removal. This improvement is mainly due to the increased concentration of abrasive at the work piece and medium. The objective of the present paper is to analysis the effect of extrusion pressure, grain size, abrasive concentration on material removal and surface finish. Electro chemical aided abrasive flow machining was possible with the help of polymeric electrolytes Dabrowski et al. 2006 [9].B.S. Brar [10] experimented with the abrasive flow machining combined with simple ECM process i.e. ECA2FM. The shape of drill bit (helical) also affects the quality of surface. Walia study the impact of central force on the abrasive flow machining process through experiments, told the relation of shaft speed, cycle index, and the grain size to improve the surface roughness and material removal amount [11–12]. Agrawal et al. [13] used poly boro siloxane as media and predicted the viscoelastic properties of media such as viscosity, creep compliance and bulk modulus. Przylenk described that with small bore diameter of work piece, more grains comes in contact with the surface, hence improves surface finish [14]. This process can be applied to finish the component up to nano level surface roughness [15].

4. Experimentation-Work

The change in material removal value is calculated as:
Change in MR= Initial weight (mg)- Final weight (mg)
The surface roughness (Ra) was depicted by Mitutoyo SJ-201 surface roughness testing machine. For experimental design, L9 (34) orthogonal array based on taguchi methodology was used. All process parameter has been studied at three levels. To measure the effect of each parameter, analysis of variance was performed for both S/N and Raw data. The material removal is higher the better type quality characteristics, So signal to noise(S/N) ratio was calculated for this type as:

$$\left(\frac{S}{N}\right)_{HB} = -10 \log (MSD_{HB})$$

Where

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$$MSD_{HB} = \frac{1}{R} \sum_{j=1}^{R} (1/y_j^2)$$

MSD represents mean square deviation, which presents the average squares of all deviations from the target value rather than around the average value.
R = Number of repetitions, y = response value

Table 1. Process parameters value at different level

S No	Parameter	Unit	Symbol	Level1	Level2	Level 3
1	Voltage	Volt	V	0	5	10
2	Molal Concentration	No.(micron)	M	0	0.25	0.5
3	Diameter of rod	mm	D	3.5	4.5	5.5
4	No. of cycle	……….	N	3	6	9

Table 2. Constant process parameters and their value

Sr.no.	Process Parameters	Range	Unit
1	Abrasive size	150	micron
2	Extrusion pressure	6	N/mm2
3	Shape of CFG rod	Triangular	------
4	Initial surface Ra	3.25-3.75	µm
5	Media flow volume	290	cm^3
6	Fixture material	Nylon	-------
7	Polymer-Gel ratio	1:1	% by weight
8	Temp. of media	32 ± 2	°C
9	Reduction Ratio	0.95	-----
10	Work piece Material	Gun metal	-----

Experimental Results

Experimental design was prepared using L9 orthogonal array based upon taguchi technique. Total 27 experiments were performed. The experimental results are shown in table 3.

Table 3. Orthogonal Array L9 with S/N and Raw data of Various Response Characteristics

S No.	V	M	D	N	R_1	R_2	R_3	S/N	Raw
1	0	0	3.5	3	2.9	2.95	2.96	9.35	9.35
2	0	0.25	4.5	6	3.1	3.15	3.22	9.98	9.98
3	0	0.5	5.5	9	3.2	3.19	3.2	10.09	10.09
4	5	0	5.5	6	5.8	5.9	5.85	15.34	15.34
5	5	0.25	3.5	9	4.8	4.9	4.75	13.65	13.65
6	5	0.5	4.5	3	3.1	3.2	3.25	10.05	10.06
7	10	0	4.5	9	5.9	5.99	5.92	15.47	15.47
8	10	0.25	5.5	3	5.5	5.2	5.4	14.59	14.59
9	10	0.5	3.5	6	3.5	3.55	3.42	10.85	10.86

The Material removal for S/N ratio & average value of raw data at three levels L1, L2, L3 for each parameter shown in table

Table 4. Main Effect (S/N & Raw data)

LEVEL	V		M		D		N	
	S/N data	Raw data	S/N data	Raw data	S/N data	Raw data	S/N data	Raw data

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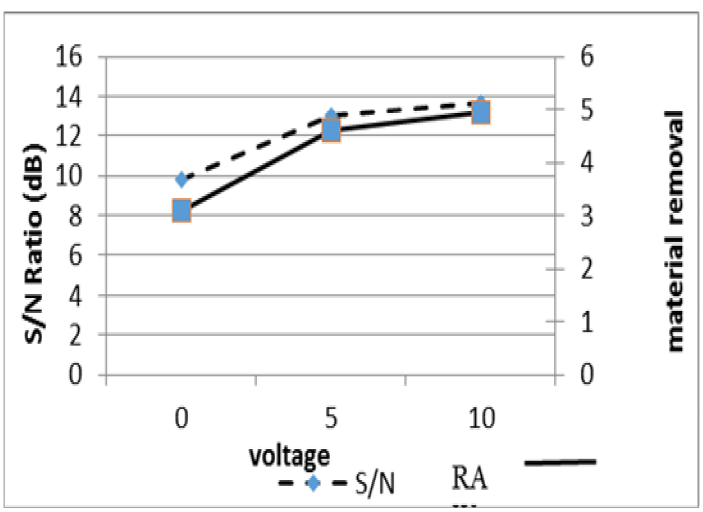
L1	13.41	5.39	19.20	12.27	22.65	15.54	21.57	15.38
L2	24.05	16.13	22.54	16.86	21.92	15.43	22.57	16.56
L3	27.78	25.04	23.51	17.43	20.68	15.57	20.86	14.61
L2-L1	10.64	10.74	3.34	4.59	-.73	-.11	1.00	1.18
L3-L2	-3.73	-8.91	0.97	0.57	-1.24	0.14	-1.71	-1.95

Where L1, L2 and L3 denotes the value of S/n & raw data at levels 1,2 & 3 of parameters.L2-L1 is the effect occurs when the corresponding parameter value changes from level 1 to level 2. L3-L2 is the effect occurs when the corresponding parameter value changes from level 2 to level 3.

5. Discussion

5.3.1 Voltage

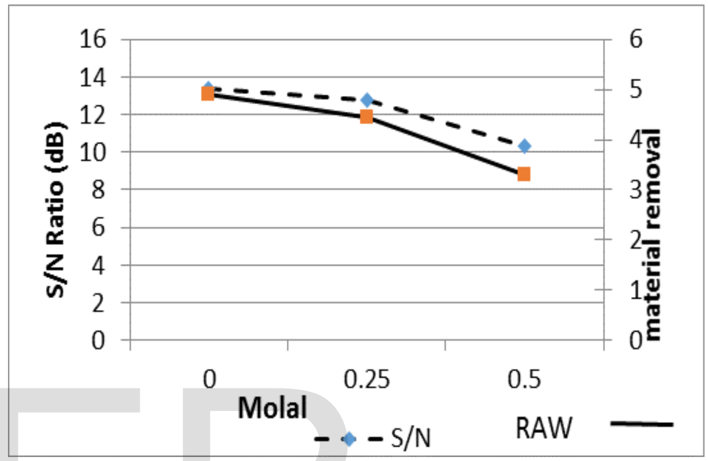
From the graph (a) it was concluded that as the votage is applied,material removal increases,material removal increases.When we applied the voltage,the enhance machining takes place due to electrolytic dissolution at the anode(workpiece).The surface becomes soft as the hard surface is eroded by electrochemical attacks. So when abrasive paticles attacks on this soft surface, material removal increases.



(a) Effect of voltage on S/N data & RAW data

5.3.2 Molal Concentration

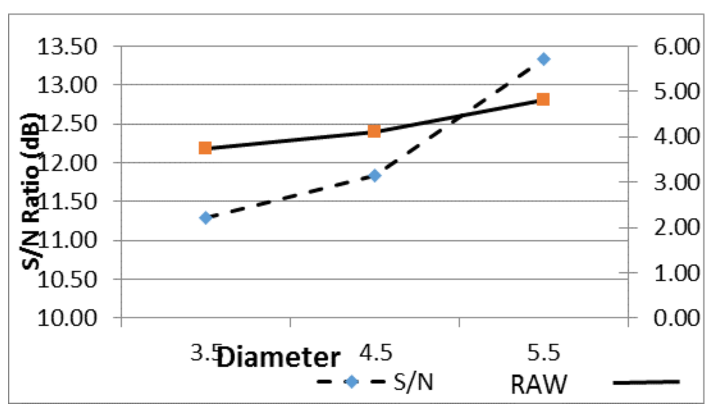
As the concentration of molal in the media increases, it increases the no. of ions available for electrochemical attack at anode (workpiece).But at the same time, it decreasess the viscosity of abrasive medium, which results in less material removal rate. Hence material removal rate decreases.



(b) Effect of molal concentrtion on S/N data & RAW data

5.3.3 Diameter of Rod

As the diameter of CFG rod increases, the gap between the workpiece and rod decreases. Then cross-sectional area through which medium was flowing decreaese & resistance to flow of medium increases. It enhance the magnitude of normal force acting on abrasive, which results in high depth of indentation. Hence more MR occurs.



(c) Effect of diameter of rod on S/N data & RAW data

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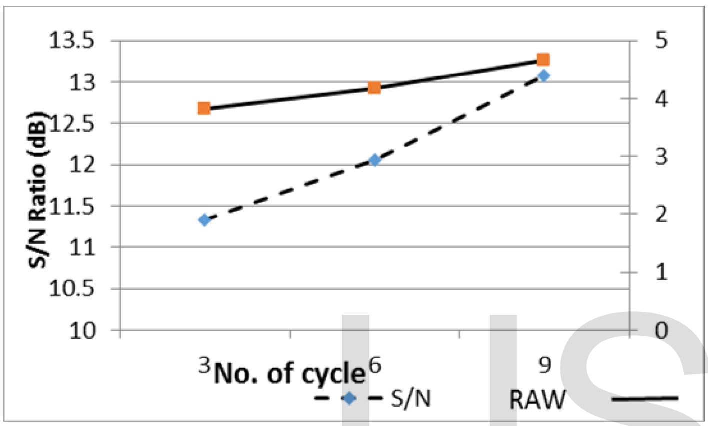
5.3.4 Number Of Cycle

It was further noticed from the graph (d) that as the number of cycles increase, MR for raw and S/N Ratio increases. As the number of cycle increases, more and more material removed from edges leading to improvement in the surface finish. Also the effect of number of cycles was significant on the basis of Raw Data and S/N Ratio Data (refer ANOVA Table).



(d) Effect of Number of cycle on S/N data & RAW data

6. Analysis

The experimental design according to larger the better which preferred to maximize the result, and the ideal target value is infinity. To study the significance of the parameters, ANOVA was performed. It was noted that % contribution of Voltage was highest (79.41) followed by Molal concentration (7.30), diameter of CFG rod (1.41), RPM (1.39) and abrasive mesh size (0.46).

Table 5.Pooled ANOVA S/N Data

Source	SS	DOF	V	P	SS'	F-Ratio
Voltage	25.30	2	12.62	48.45	20.72	5.52
Molal	15.56	2	7.78	29.78	10.98	3.40
Diameter of rod	POOLED					
No. of cycle	6.79	2	3.39	12.99	2.21	1.48
Error	4.58	2	2.29	8.87	29.30	
Total	52.23	8		100.00	52.23	

Table 6.Anova Raw Data

Source	SS	DOF	V	P	F-Ratio
voltage	17.32	2	8.66	45.35	1599.68
Molal	12.50	2	6.25	32.72	1154.53
Diameter of rod	3.067	2	1.53	8.02	283.18
No. of Cycle	5.23	2	2.61	13.65	482.69
Error	0.10	18	0.005	0.25	
Total	38.218	26		100.00	

SS- Sum of square, dof-degree of freedom, V-variance, SS'-pure sum of square. *Significant at 95% confidence level, Fcritical = 3.4928.

7. Conclusion

The following conclusion was noticed from the results:

The voltage has highest contribution (45.35%) for raw and (48.45%) for S/N data towards material removal.

The contribution of Molal concentration is (32.72%) for raw data and (29.78%) for S/N data.

Diameter of CFG rod is also significant and shows (8.02 %) contribution for raw data. Number of cycle has (13.65%) contribution for material removal.

The optimal parameter for effective material removal was observed as V3M1D3N3.

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It has been observed that material removal rate can be enhanced by clubbing simple AFM process with ECM. Further better results can be obtained by varying parameters at different levels or by club magnetic AFM process with ECAFM or CFAAFM.

Reference

[1]. Rhoades L.J., "Abrasive flow machining with not-so-silly putty", Metal Finishing, (1987), pp.27-29.

[2]. Rhoades L.J., Abrasive flow machining, Manufacturing Engineering, (1988), pp.75-78.

[3]. Rhoades L.J., Abrasive flow machining: A case study, J. Material Processing Technology, 28, (1991), pp.107-116.

[4]. Perry W.B., Abrasive flow machining – principles and practices, Non-traditional conference proceedings, (1989), pp.121-127.

[5]. Williams R.E.and Rajurkar K.P. "Stochastic modeling and analysis of Abrasive flow machining", Transaction ASME, Journal of Engineering for Industry,114,1992,74-78

[6]. Jain V.K; Adsul. S.G; "Experimental investigations into abrasive flow machining "International Journal of Machine tool and Manufacturing,40,2002,1003-1021

[7]. Loveless T.R,Williams R.E and Rajurkar K.P;"A study of the effects of Abrasive Flow finishing on various machined surfaces. Journal Material processing technology,47,1994,133-151.

[8]. Sing S.Shan H.S; Development of magneto abrasive flow machining process, International Journal of Machine Tool and Manufacture,42,2002,953-959

[9]. Lucjan Dabrowski; "Advancement of abrasive Flow Machining Using an Anodic Solution", Journal of New Materials for Electrochemical Systems(2006) , pp 439-445

[10]. B.S. Brar, R.S. Walia and V.P. Singh; "Electro Chemical Machining in the Aid of Abrasive Flow Machining Process", International Journal of Surface Engineering & Materials Technology, Vol. 2 No. 1 Jan.-June 2012, pp 5-9.

[11]. .R.S.Walia, H.S.Shan and P.Kumar, "Enhancing AFM process productivity through improved fixturing, "International Journal of Advanced Manufacturing Technology,vol.44,no.7-8,pp.700– 709,2009.

[12]. S. Singh, H. S. Shan, and P. Kumar, "Experimental studies on mechanism of material removal in abrasive flow machining process," Materials and Manufacturing Processes, vol. 23, no. 7, pp.714–718,2008.

[13]. Agrawal A., Jain V.K., Muralidhar K., "Experimental determination of viscosity of abrasive flow machining media", International Journal of