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Experimental Comparison of Abrasive Flow Machining and Magnetic Abrasive Flow Machining for Aluminium Tubes

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Abstract - The recent increase in the use of hard, high strength and temperature resistant materials in engineering necessitated the development of newer machining processes. Abrasive flow machining (AFM) is a non-traditional finishing process in which an abrasive-laden viscoelastic polymer is forced across the work piece surface where as magnetic abrasive flow machining (MAFM) is a hybrid AFM process which utilizes the magnetic energy for finishing. The surface finish of the order of nanometric level can be achieved by this process. Magnetic abrasive machining of stainless steel pipes has been known very well in the process of finishing to fine finish standard. However, its applications in softer materials such as Aluminium were difficult due to soft metal characteristic itself. In the present work, the machining capabilities of the abrasive flow machining and magnetic abrasive flow machining have been compared for Aluminium tubes using mechanically alloyed magnetic abrasives. It has been found that the percentage improvement in surface finish (PISF) is better in magnetic abrasive flow machining as compared to abrasive flow machining. Surface roughness of the finishing surface was recorded and studied.

***Keywords**: Abrasive flow machining (AFM), Magnetic Abrasive Flow Machining (MAFM), PISF, abrasive-laden viscoelastic polymer, Aluminium Tube, Surface Roughness.*

I. INTRODUCTION

The conventional methods of finishing such as grinding, lapping, honing and super-finishing take care of the dimensional and alignment accuracy and the quality of the surface finish. But, these conventional finishing processes are limited to the production of basic shapes such as flat, cylindrical, etc. On the other hand, non-conventional machining (NCM) processes are helping the industry to attain the required degree of accuracy and surface finish. NCM processes are also capable of machining difficult to machine materials and intricate shapes. NCM processes are a group of processes that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies. In mechanical processes, unwanted material in the workpiece is removed by mechanical action. In electrochemical processes, unwanted portions of the workpiece are removed by electrochemical effect. The workpiece (in contact with an electrolyte) is machined by ion dissolution. In chemical processes, chemical energy is used to remove material from the workpiece. Material is removed by controlled etching of the workpiece in the presence of a reagent known as etchant. In electro-thermal processes, electrical energy is converted to a huge amount of heat by some means. This heat is applied on a small region of the workpiece. That particular region is either melted or vaporized. By this way, material is removed. Each process has its own advantages and limitations. As far as the range of materials to be machined by these processes is concerned, the mechanical type NCM processes have more capabilities.

In 1960s, The Abrasive Flow Machining (AFM) process is originally developed by Extrude Hone Corporation, USA. Abrasive Flow Machining (AFM) is a non-traditional finishing process that in which an abrasive-laden viscoelastic polymer is forced across the work piece surface. But abrasive flow machining has some drawbacks like low material removal rate, Surface irregularities such as scratches, bumps, more number of cycles is required for high material removal rate etc. To overcome these drawbacks, a hybrid AFM known as Magnetic abrasive flow machining (MAFM) [12] is introduced in which Magnetic field is used around the AFM setup. The surface finish of the order of nanometric level can be achieved by this process.

II. LITERATURE SURVEY

Among various mechanical NCM processes, Abrasive flow machining (AFM) is one of the non-conventional machining process [1], [11] that is used for deburring, radiusing, polishing and removing recast layer. AFM ensures the component accuracy, process efficiency and economy and effective automation. The product performance and lifetime can be dramatically improved by the edge quality and surface finish. Removing stress raisers at sharp corners by producing controlled radii on edges can substantially improve thermal and mechanical fatigue strength of highly stressed components. Additional advantages over conventional finishing processes include better control with regard to the accuracy of machined surfaces. The complex passages and the areas which are inaccessible to conventional methods can be finished to high quality by this process. The process covers a wide range of feasible applications including dies and moulds, automotive parts, aerospace and medical components etc.

Fox et al. [2] concluded that unbounded magnetic abrasive particle (UMAP) yield higher material removal rate (MRR) and bounded magnetic abrasive particle gives better surface roughness. Surface roughness value (Ra) of a ground rod has been achieved as low as 10 nm. Shankar et al. [3] performed experiments on Metal matrix composite (MMC-aluminum alloy and its reinforcement with SiC) using AFM. It has been found that material removal increases with increase in extrusion pressure and number of cycles while decreases with increase in processing oil content in the medium in AFM and mechanism of finishing and material removal in case of alloys was different from that in case of MMC when finished by AFM process. Sankar et al. [4] experimentally investigated rotating workpiece AFM. It has been concluded that rotational speed of workpiece has significant effect on output responses (Ra) and Δ*R*a increases with increase in the number of cycles, extrusion pressure till 6.5MPa and processing oil content till 10%. Better *R*a was achieved on Al alloy/SiC (10%) MMC among three workpiece materials by AFM. Singh et al. [5] investigated Magneto Abrasive Flow Machining (MAFM) process to improve the material removal rate and reduces surface roughness by applying a magnetic field around the workpiece. ANOVA technique has been used to identify the most significant parameters - magnetic flux density, volume flow rate, number of cycles, medium flow volume, abrasive grit size, abrasive concentration and reduction ratios. It has been found that MAFM gave significantly improved performance over AFM and magnetic field significantly affects surface roughness and material removal rate. Kamble et al. [6] used magneto abrasive flow machining for increasing surface finish and material removal rate. It has been concluded that magnetic field significantly affects both MRR and surface roughness. Higher improvement in MRR is expected at higher values of magnetic field. The interaction of low flow rates and high magnetic flux density yields more MRR and smaller surface roughness. Jha et al. [7] investigated the effect of magnetic flux density on the surface finish improvement. It has been found that, at zero magnetic field conditions no improvement in surface finish is observed, and significant improvement is at high magnetic field strength. R. Singh et al. [8] developed a non-traditional micro-machining process known as Abrasive flow machining (AFM) as a method to deburr, radius, polish and remove recast layer of components in a wide range of applications. It has been found that material is removed from the work-piece by flowing a semi-solid viscoelastic plastic abrasive laden medium through or past the work surface to be finished. Components made up of complex passages having surface/areas inaccessible to traditional methods can be finished to high quality and precision by this process. Jain et al. [9] studied the MAF process on stainless steel workpiece with loosely bounded magnetic abrasives. It has been concluded that circumferential speed and the working gap significantly affects the surface roughness value (Ra).

III. EXPERIMENTAL DETAILS

A. *Experimental setup*

The experimental setup is a modified version of the existing AFM setup by applying two Electromagnets on the sides of work piece. It is a two-way MAFM Setup and the major components of set up are couple of hydraulic cylinders, Electromagnets, Control unit, rotary gear pump, A.C. motor, D.C. valve, , pressure reducing valve, flow control valve, , pressure gauge, oil filter, , limit switch, hydraulic oil and oil tank.

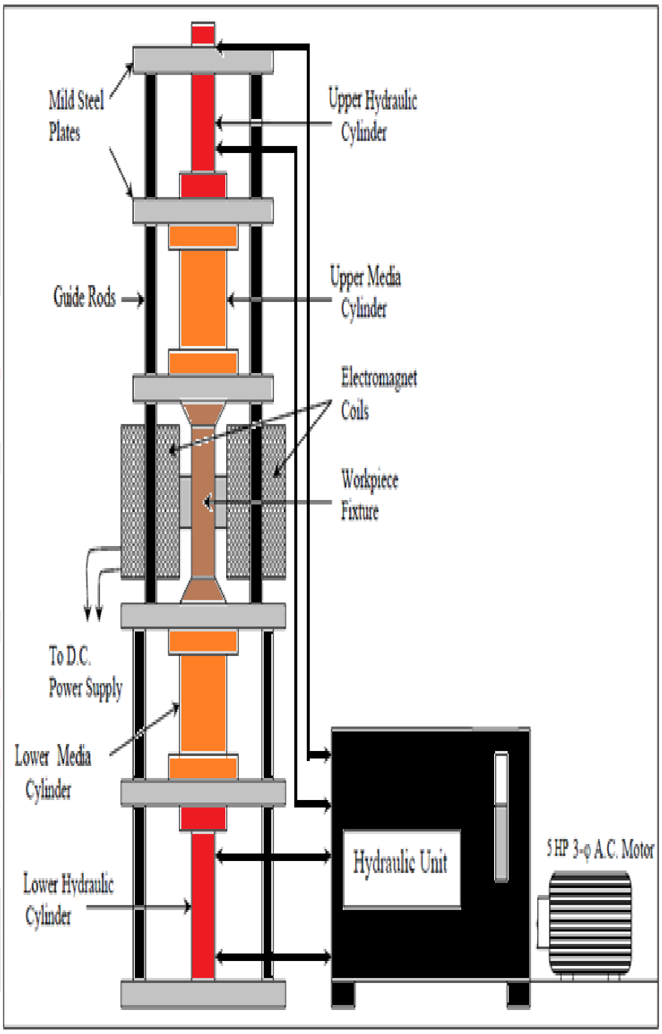

Figure 1: Schematic illustration of magnetic abrasive flow machining (MAFM) process

Figure 1 shows an experimental set-up of MAFM. It has two hydraulic cylinders and two medium cylinders. The medium is extruded, hydraulically or mechanically, from the filled chamber to the empty chamber via the restricted passageway through or past the work piece surface to be abraded. Typically, the medium is extruded back and forth between the chambers for the desired fixed number of cycles. Counter bores, recessed areas and even blind cavities can be finished by using restrictors to direct the medium flow along the surfaces to be finished.

The key components of MAFM are the machine, the tooling, types of abrasives, media composition, and electromagnet. Magnetic field, extrusion pressure, number of cycles, abrasive grit composition and type, and fixture design are the process parameters that have the largest impact on MAFM results. The viscosity of polymeric medium plays an important role in finishing operation. This allows it to selectively and controllably abrade surfaces that it flows across. The work piece held by fixture is placed between two medium cylinders which are clamped together to seal so that medium does not leak during finishing process.

B. MAFM Principal & working

Abrasive action accelerates by change in the rheological properties of the medium when it enters and passes through the restrictive passages. The viscosity of polymeric medium plays an important role in finishing operation. This allows it to selectively and controllably abrade surfaces that it flows across. The work piece held by fixture is placed between two medium cylinders which are clamped together to seal so that medium does not leak during finishing process.

The magnetic abrasive particles are joined to each other magnetically between the magnetic poles S and N along the lines of magnetic power, framing flexible magnetic abrasive brush. This setup is being utilized for the inside polishing of aluminum pipe. The magnetic abrasives containing medium is permitted to travel through the aluminum workpiece from the upper medium containing barrel to the lower one. The medium is pulled in by the magnetic field around workpiece which builds the polishing power and subsequently material is removed.

The magnetic abrasives are developed by mechanically alloying (MA) technique. Mechanical alloying is one solid state powder processing technique involving repeated welding, fracturing and rewelding of powder particles in a high energy ball mill or attritor. After MA, Sintering of ferromagnetic iron powder and abrasive powder (Diamond) at a high temperature in H_2 gas atmosphere is done which is at that point blended in a definite rate with the medium. This magnetic abrasive laden medium causes finishing inside the pipe along the lines of magnetic field and gives important machining power inside the workpiece. The space amongst workpiece and the electromagnet is kept constant.

C. Experimental Conditions

In this work diamond based sintered magnetic abrasives were mixed with laden medium [10] for internal finishing of cylindrical brass pipes. Diamond powder is used in this experimentation as an abrasive particle, which is externally purchased from the vendor. The average grain size of this abrasive powder is supposed to 200 mesh number. Mixing of iron powder and diamond powder is done in the ratio of 4:1. For smooth internal surface finishing of aluminium tube, abrasive laden media is prepared in the lab with constituent's polyborosioxane, gel and abrasives. The polymer to gel ratio is taken as 70% by weight and abrasive to media concentration is taken as 50% by weight. The experimental conditions are shown in table1. Cylindrical Aluminium pipes (Ø16mm × Ø8mm × 50mm) were used for the experiments as workpieces. Important process parameters that may significantly affect the finishing force/torque, surface roughness were identified. The major influential parameters/experimental conditions which were kept in mind and also on board before & during the experimentation are number of working cycles, extrusion pressure, Initial surface finish R_a same, and measured PISF% i.e. Percentage Improvement in Surface Finish (PISF%), Material Removal Per Cycle (MRC) and MRR for the MAFM setup. The table 1 shows the experimental conditions after performing preliminary experiments.

Table1: Experimental Conditions for AFM and MAFM

Workpiece Material	Aluminium (Ø16mm × Ø8mm × 50mm)
Magnetic Abrasives	Iron Poweder (200 mesh size) + Diamond Powder (200 mesh size)
Magnetic Abrasive Laden Medium	Magnetic Abrasives + Polymer and Gel (70%)
Electromagnet and workpiece distance	5mm
Extrusion Pressure	700, 900, 1100
No. of cycles	5, 15, 25, 35, 45, 55

D. Procedure of Experiments

The experiments were conducted for AFM and MAFM for the input parameters as shown in tables 2, 3 and 4. The experiments were aimed at considering the effects of several controllable factors on surface roughness. The finishing characteristics were analysed by measuring the surface roughness, which was measured at four points before and after finishing using a Mitutoyo surface roughness tester (SJ-210P) having a least count of 0.001 µm (cut off length = 0 .8 mm) and averaged. Multiple observations on surface roughness are taken for every experimental condition and an average of these observations is taken as the final value of response. To get uniform finish over the workpiece surface, the number of cycles of the machine and extrusion pressure was adjusted. The homogenous mixture of mechanically alloyed magnetic abrasive particles which is also called magnetic abrasive laden medium (iron particles, diamond powder plus polymer gel) was prepared [10] just before the start of each experiment for AFM and MAFM.

Figure 2: Two way MAFM Apparatus

IV. RESULTS AND DISCUSSIONS

The experiments were conducted on each pressure value of 700 psi to 1100 psi and for increasing no. of cycles (5-55 with a gap of 10) on different specimens of Aluminium by AFM and MAFM setup. The table 2 shows the PISF value

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achieved by AFM and MAFM at extrusion pressure of 700 psi for increasing no. of cycles from 5-55 with a gap of 10.

Table 2: Effect of no. of cycles on PISF on extrusion pressure 700 psi

S. NO.	Extrusion Pressure (psi)	No. of Working Cycles	PISF % (AFM)	PISF % (MAFM)
1	700	5	10.8	12.3
2	700	15	19.8	22.1
3	700	25	28.3	29.5
4	700	35	32.4	34.4
5	700	45	37.1	38.4
6	700	55	39.1	40.3

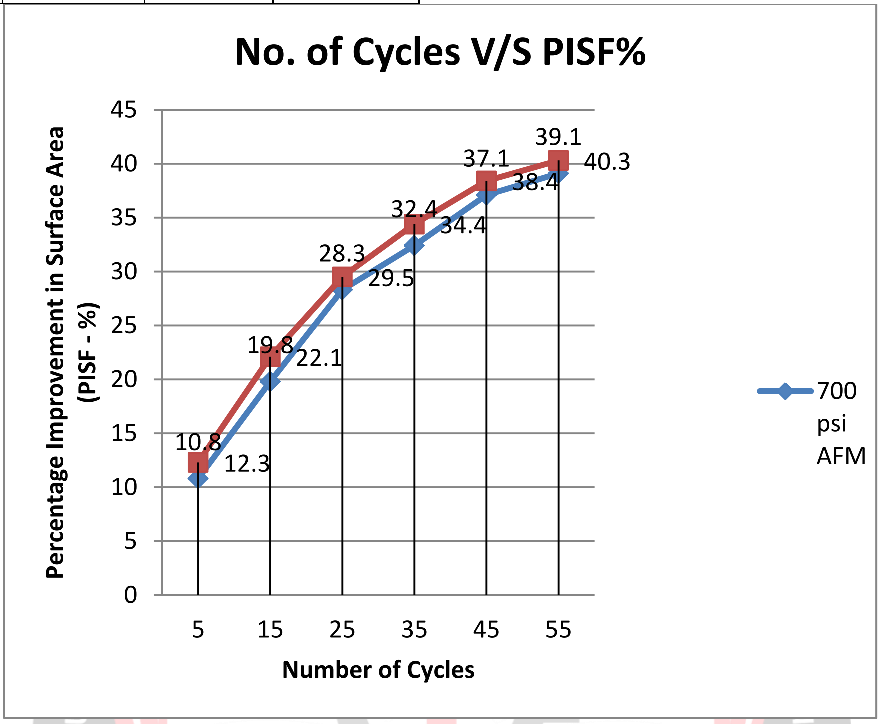

Figure 3: Comparison of AFM and MAFM on extrusion pressure 700 psi

Figure 3 shows that at extrusion pressure of 700 psi, for increasing no. of cycles the value of PISF value goes on increasing. Also at same values of no. of cycles, the PISF is better for MAFM than AFM.

The table 3 shows the PISF value achieved by AFM and MAFM at extrusion pressure of 900 psi for increasing no. of cycles from 5-55 with a gap of 10.

Table 3: Effect of no. of cycles on PISF on extrusion pressure 700 psi

S. NO.	Extrusion Pressure (psi)	No. of Working Cycles	PISF % (AFM)	PISF % (MAFM)
1	900	5	19.2	22.7
2	900	15	23.1	26.5
3	900	25	34.1	40.3
4	900	35	40.2	43.6
5	900	45	43.1	46.1
6	900	55	43.8	46.9

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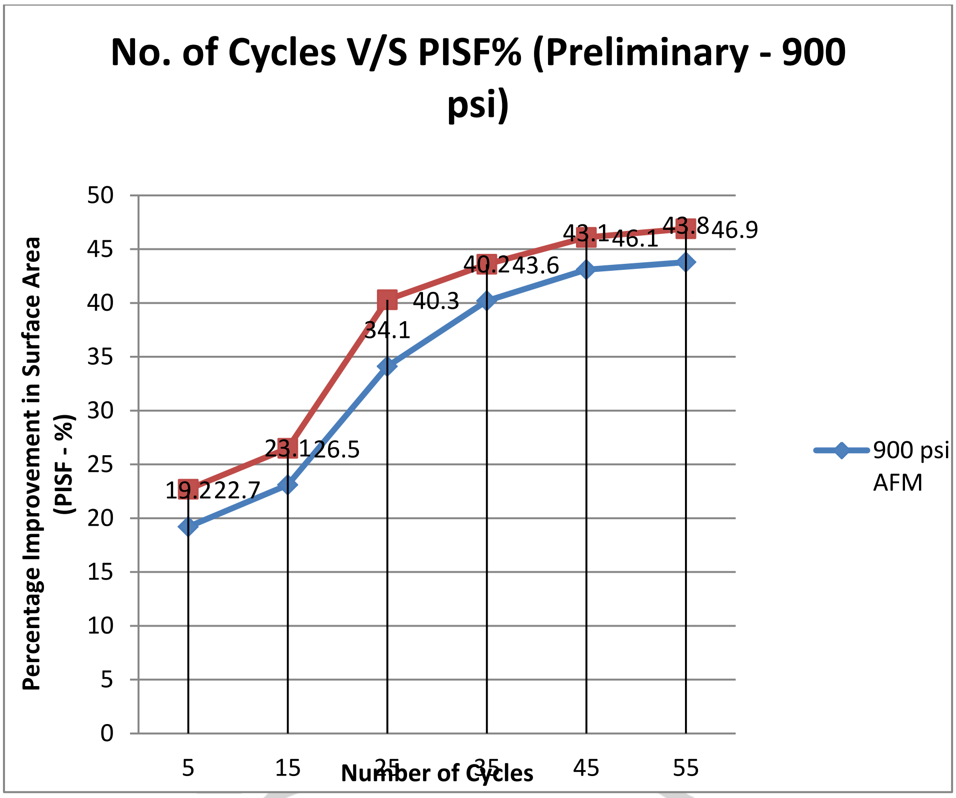

Figure 4: Comparison of AFM and MAFM on extrusion pressure 900 psi

Figure 4 shows that at extrusion pressure of 900 psi, for increasing no. of cycles the value of PISF value goes on increasing. Also at same values of no. of cycles, the PISF is better for MAFM than AFM.

The table 3 shows the PISF value achieved by AFM and MAFM at extrusion pressure of 1100 psi for increasing no. of cycles from 5-55 with a gap of 10.

Table 4: Effect of no. of cycles on PISF on extrusion pressure 1100 psi

S. NO.	Extrusion Pressure (psi)	No. of Working Cycles	PISF % (AFM)	PISF % (MAFM)
1	1100	5	17.3	20.2
2	1100	15	25.2	30.1
3	1100	25	39.2	45.2
4	1100	35	42.3	48.3
5	1100	45	49.3	57.4
6	1100	55	51.2	59.2

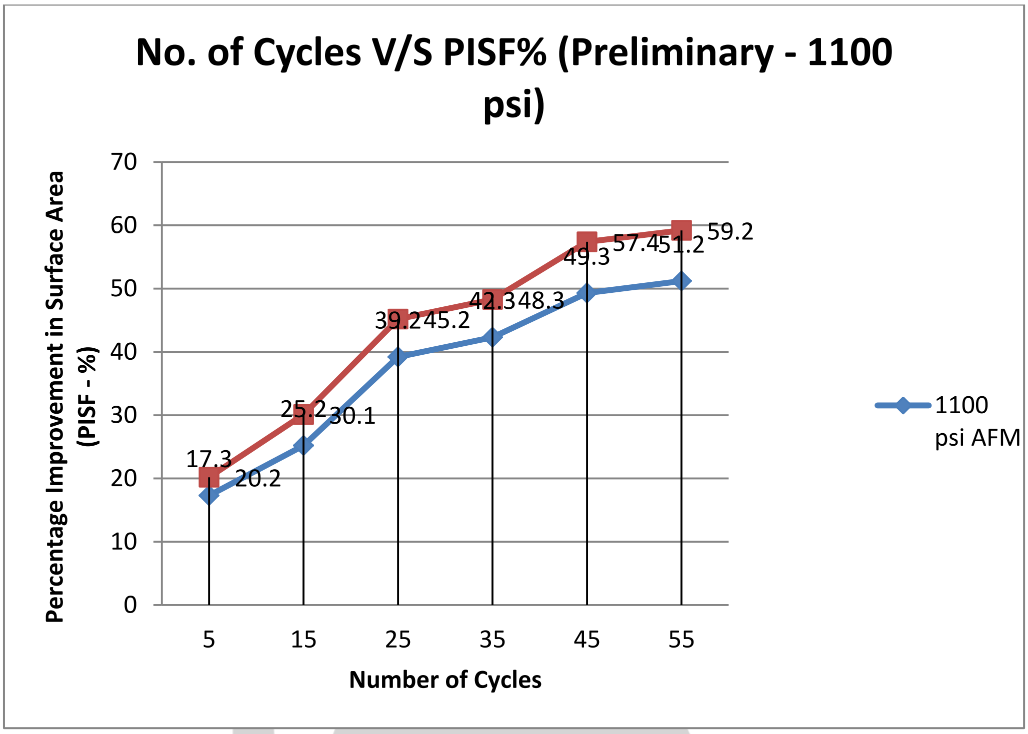

Figure 5: Comparison of AFM and MAFM on extrusion pressure 1100 psi

Figure 5 shows that at extrusion pressure of 1100 psi, for increasing no. of cycles, the value of PISF value goes on increasing. Also at same values of no. of cycles, the PISF is better for MAFM than AFM and the best PISF of 59.2% has been achieved for MAFM at extrusion pressure of 1100 psi at 55 no. of cycles.

V. MICROSTRUTURE EXAMINATION

To further study the comparison between AFM and MAFM, AFM and MAFM finished surfaces of Aluminium tubes were microscopically examined using scanning electron microscopy (SEM). SEM is a type of electron microscope that images the sample surface by scanning it with a high energy beam of electrons in a raster scan pattern. Figures 6 (a) and (b) show the SEM micrograph of AFM finished surface and MAFM finished surface respectively. The observations reveal that the finishing of workpiece surface in this process is done by scratching or micro-cutting. It is quite clear from figure 6(a) that most of the scratches after the AFM operation have been removed and replaced by the new texture generated during the MAFM process as shown in figure 6(b), but fine scratching marks produced by MAF appear on the surface. Most of the peaks have been sheared off to much smaller height by MAFM resulting in improved surface finish. It can be clearly seen from figure 6(b) that fine surface finish has been achieved by MAFM.

Figure 6(a) SEM micrograph of AFM finished surface (b) SEM micrograph of MAFM finishing surface

VI. CONCLUSIONS

After AFM and MAFM of Aluminium tubes by using Diamond based magnetic abrasive laden media, it has been concluded that the process yields best results for PISF = 51.2 % at extrusion pressure = 1100 psi and no. of cycles = 55 for AFM setup and at same parameters for MAFM Setup, the process yields best results for PISF = 59.2 %. This means MAFM shows improvement over AFM. The extrusion pressure has a predominant effect on the PISF. The value of PISF is more on high extrusion pressures than low extrusion pressures. For higher no. of cycles, improvement in surface finish becomes almost constant. SEM micrographs show better surface finish of MAFM finished surface than AFM.

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