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# Abrasive Jet System And Its Various Applications In Abrasive Jet Machining, Erosion Testing, Shot-Peening, And Fast Cleaning

Barun Haldar[a]*, Tina Ghara[b], Rasid Ansari[c], Santanu Das[d], P.Saha[e]

[a]*School of Mechanical Engineering, Jimma Institute of Technology, Jimma University, Jimma-378, Ethiopia*
[bcd]*Department of Mechanical Engineering, Kalyani Govt. Engineering College, Kalyani, Nadia-741235, WB, India*
[e]*Department of Mechanical Engineering, Indian Institute of Technology, Kharagpur-721302, WB, India*

**Abstract**

Abrasive jet system is one of the effective tools and found several present and future applications in many manufacturing industries and R&D sectors. In the form of abrasive jet it is used for machining like cutting, drilling, and engraving of brittle materials. Surface fast cleaning and preparation are done by using abrasive jet for welding and plasma spray coatings. The erosion tests of turbine blades, propellers are done by using abrasive jet application. Some special type of particles are used for shot peening for surface hardening. An abrasive jet system is in-house designed and manufactured and its performance is observed in various applications like machining, cleaning, and erosion tests. In this present research work, a critical review has been done on various applications of abrasive jet systems. Based on the present status of work, the application possibilities of the present abrasive jet system is experimentally evaluated. It is evident that the abrasive jet system using natural sand can be used for cutting, drilling and engraving of brittle material like glass, marble, etc. Rust cleaning from the metal surface and erosion tests of metal matrix composite laser coatings are also performed by using the same abrasive jet system.

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*Keywords:* *Abrasive jet machining, erosion testing, surface cleaning, surface preparation, shot-peening*

## 1. Introduction

The kinetic energy in a stream of abrasive particles carried by a high velocity gas, can strike the work surface and the work material is removed by means abrasion which is micro-fracture due to impact of the abrasive particles [1,

* Corresponding author. Tel.: +251-472115013; fax: +251-472115013.
*E-mail address:* dr.barun.haldar@ju.edu.et

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2]. The jet with high velocity of abrasives is generated by converting the pressure energy of gas or air to the kinetic energy. The system which generates a high velocity jet of abrasives can be used in many applications. Utilizing the kinetic energy of the abrasive jet and by doing some modifications in the system, various types of operations like cutting of hard materials, erosion tests, shot-peening, cleaning, etc. are practiced efficiently.

In machining, the abrasive jet system is used for machining hard and brittle materials. Different types of operations done by this system are cutting of hard materials, drilling on glass and ceramic materials, grooving, engraving, etc.

Wearing and erosion particularly are problems that reduce service life of a product. So, testing of erosion resistance of products before it is being used is essential. Abrasive jet system provides a suitable means for erosion test of turbine blades, weldments, different parts of thermal power plant, etc.

Some special types of operations like welding, plasma spraying, laser cladding, etc., need surface preparation for good bonding of the deposited material with the substrates. Abrasive jet system can is used for grit blasting by which abrasive particles are used to clean or modify its surface properties by impinging the particles on the surface.

Shot peening is a mechanical process used to build a compressive residual stress layer and improve mechanical properties of metals and composites. It is done by impacting a surface with shots (round metallic, glass, or ceramic particles) with a force which is enough to produce plastic deformation. In industries, removal of tensile residual stress and to induce compressive residual stress which results in hardening of machine tool bed, gear teeth, machine elements, etc. shot-peening is essentially used.

Abrasive jet processing is useful in various engineering and research sectors. To develop an abrasive jet system may be a scope of work for experimental investigations as well as technology transfer to the society. In this present work, a comprehensive review has been made to find out various scopes of recent applications of abrasive jet system in industries. The developed abrasive jet system is efficient to cut and drill brittle materials, to clean surface, to test erosion resistance of coatings, and others.

## 2. Some investigations on Abrasive Jet processing

### *2.1. Present status of Abrasive Jet machining*

Search and review show several works were done on Abrasive Jet Machining (AJM). Some researchers did experiments on cutting, while some worked on drilling. Some papers consist of the characteristic study about the process parameters influencing the machining process. Park et al. [3] described the performance of micro-AJM in micro-grooving of glass. A hole-type groove with 80μm diameter and line-type groove with the same width were machined. It was observed that the experimental results showed satisfactory performance in micro-grooving of glass, and the size of the groove increased about 2-4μm than the required dimension. It was also observed that the groove profiles became U-shaped due to the characteristics of Micro-AJM. Surface roughness of the hole-type groove was found to be about $R_a$= 0.8μm and for the line-type groove, surface roughness was $R_a$= 0.6 μm. They also suggested that micro-AJM process could be efficiently used for machining of semiconductors, electronic devices and LCD with effective masking process and the compensation for film wear. El-Domiaty et al. [4] carried out drilling of glass sheets with different thicknesses by abrasive jet machining. A mathematical model for drilling has been introduced and experimental validation was established. Micro-holes developed by micro abrasive jet machining were usually tapered due to the tapering effect of the abrasive jet. Abhishek and Hiremath [5] presented a novel approach for machining holes in quartz, using micro abrasive jet machine to reduce the tapering effect. The nozzle was fed at a rate equal to the average rate of change of the thickness of the workpiece. It was found that the entrance diameter of the machined hole was reduced by 29% and the taper angle of the hole was reduced by approximately 58% with improved cylindricity. Srikanth et al. [6] conducted experiments by abrasive jet drilling of glass sheets using different SOD's, pressure and different nozzle diameters to assess its machinability under different process parameters of the AJM process. The effect of process parameters on MRR was analyzed by Taguchi method. Better MRR was identified at air pressure of 8 kg/cm$^2$, 10 mm SOD and Nozzle diameter of 4 mm and better kerf was found at 6 kg/cm$^2$ air pressure, 9 mm SOD and a nozzle diameter of 3 mm. A semi-empirical equation to obtain the shape of the surface generated in AJM was derived by Balasubramaniam et al. [7]. It was shown that the shape of the abrasive jet machined surface had reverse bell mouthed type with an edge radius at the entry side of the target surface. Also it was observed that the entry side diameter increased with the input parameter, and with increase in the peripheral velocity of the jet, the edge radius increased. Gradeen et al. [8] investigated the temperature dependence of the abrasive jet machining of Polydimethylsiloxane between temperatures of -178°C and 17°C for different angle of attack using a cryogenic abrasive jet machining apparatus taking $Al_2O_3$ particles. It was reported that the efficient machining of Polydimethylsiloxane (PDMS) occurred at approximately -178°C and at angles of attack between 30°-60° from the surface. They also found out that though the machining of PDMS could be done above the glass transition temperature, the erosion rate was more (increased by factor 10) when the temperature was below the glass transition temperature. Wakuda et al. [9] attempted to identify the material response to abrasive particle impact during abrasive jet machining of alumina ceramics. They used three kinds of commercial abrasive particles for indentation in sintered alumina samples and they observed that the material response to particle impact depended remarkably on the abrasives employed. Srikanth et al. [10] also used Taguchi's method and ANOVA to optimize the AJM process parameters on ceramics for efficient machining. They found that the process parameters had remarkable influence on MRR and kerf. Their analysis suggested that the pressure predominantly affects the MRR but Stand-of-Distance affects the kerf. In another work, Reddy et al. [11] focused on optimization of the process parameters in AJM process. They performed the experiment on Rayon based CFRP composite using silicon carbide abrasive and analyzed the response surface to optimize the process parameters. Abrasive jet machining using silicon carbide abrasive was conducted by Mahajan [12] to study the influence of AJM process parameters on MRR and diameter of holes of glass plates. It was observed that with increase in SOD, the upper surface diameter and lower surface diameter of holes increased. Also MRR increased with pressure. Ke et al. [13] presented a hybrid method that magnetic abrasive with elasticity which was self-made, was utilized to analyze machining characteristics in AJM. It was found that the flexible magnetic abrasive not only retained the abrasive jet direction to enhance MRR, but also had slip-scratch effect to obtain better surface finish than conventional machining. In a different type of work, Oancea et al. [14] worked on the modification of nozzle for abrasive jet engraving in micro machining process. The problem of modifying a sand blasting gun in order to use it for abrasive machining with thinner jets was formulated. The designed solution was achieved through some experimental work.

The present authors designed and fabricated an abrasive jet system enabling multi-tasking ability like AJM, slotting, drilling, erosion testing, and surface preparation. The control panel and nozzle-work piece interface of the said set-up is shown in fig. 1 and fig, respectively.

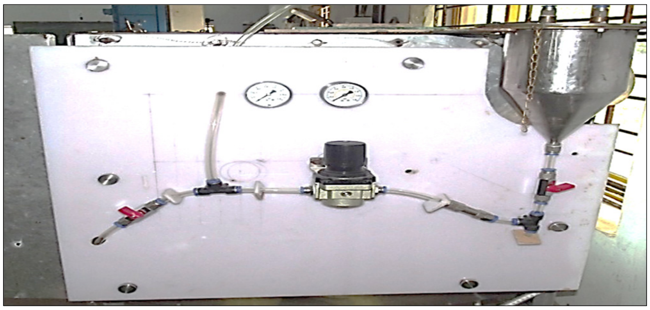


Fig.1. Photograph of the control panel of abrasive jet system

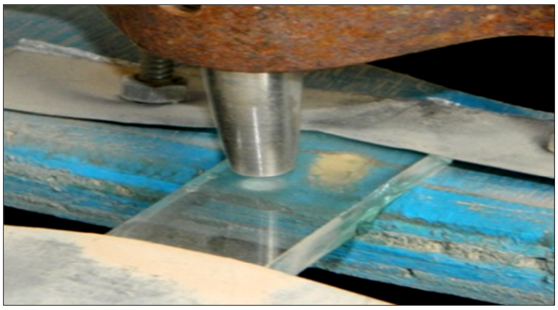


Fig.2. Nozzle-work piece combination during operation

## 2.2. Present status of erosion testing and analysis

Some researchers worked on erosion testing and analysis. Jafar et al. [15] conducted experiments to assess the surface roughness and erosion rate of abrasive jet micro-machined channels. The effect of abrasive particle size, velocity of jet and angle of attack on the roughness of machined channels in borosilicate glass using AJM was presented in their paper. It was also demonstrated that the erosion and surface roughness per particle impact were proportional to the kinetic energy of the particle. Wear characteristics of the (W, Ti)C/ SiC gradient ceramic nozzle was investigated by Jianxin et al. [16], and the result was compared with a conventional ceramic nozzle. They found the mechanism responsible for wearing to be the tensile stress that was reduced at the entry region compared to the conventional nozzle. Results showed that the gradient ceramic nozzles had higher wear resistance property over conventional ceramic nozzles. Fan et al. [17] developed predictive mathematical models for assessing the erosion rates in drilling of micro-holes and micro-channel cutting on glasses with an abrasive jet. They used a technique for formulation of the models as a function of the properties of the target material impact parameters and the process parameters affecting the erosion of brittle materials. It was shown that model predictions were similar to some extent to the experimental results with a deviation of 1%.

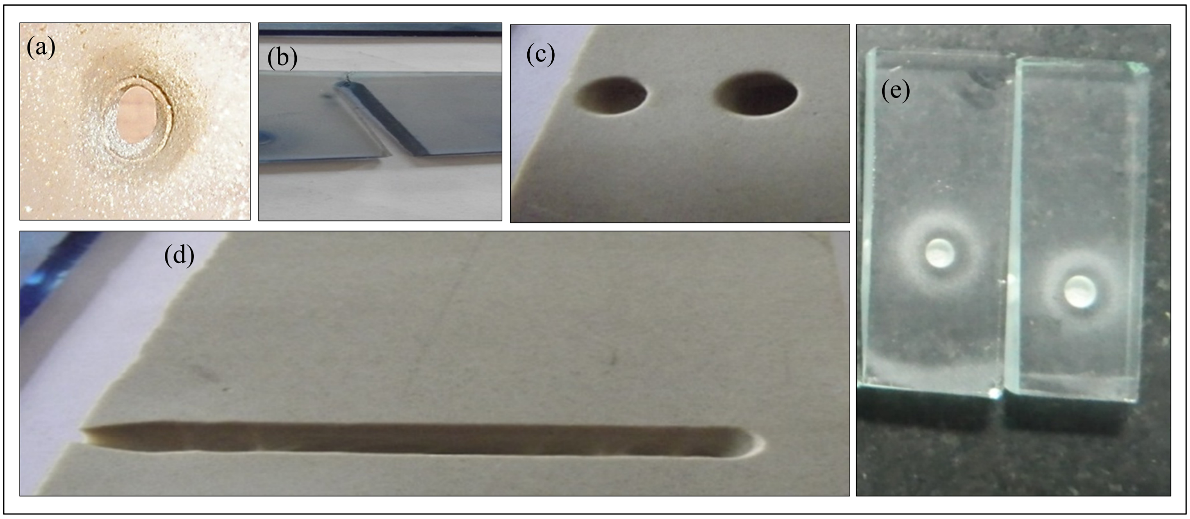
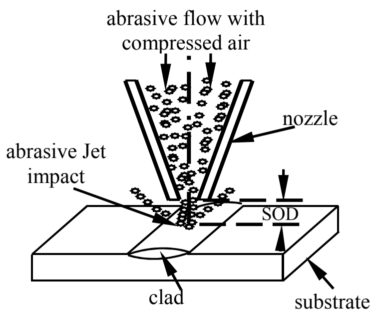



Fig.3. Some machining operations using the fabricated abrasive jet system (a) drilling hole on glass, (b) cutting of glass, (c) hole on tiles , (d) cutting of tiles, and (e) engraving on glass

A comparative erosion wear tests was conducted by the present authors on bare Ti-6Al-4V samples and on laser clad surface (titanium boride and titanium carbide reinforced Ni-Ti matrix MMC coating). Degradation of material by erosion is one of the adverse situation in propeller, turbine blades etc. An erosion studies were conducted both on the bare Ti-6Al-4V substrate and the laser cladded surface under same condition (which is described in table1) to examine the stability of the coating against air suspended highly mobilized hard particles.

Table 1. Erosion wear process mechanism and process parameters

| *schematic of erosion mechanism* | *process parameters* | |
|---|---|---|
|  | nozzle material: | SS |
| | nozzle convergence: | 15$^o$ |
| | nozzle opening: | 1 mm |
| | stand-off distance (SOD): | 4 mm |
| | working pressure: | 5 bar |
| | abrasive material: | $SiO_2$ |
| | abrasive size( $R_p$): | 150 – 200 μm |
| | abrasive flow rate: | 500 g/min |
| | time of erosion: | 20 s |



Due to the abrasive impact, the sharp craters were formed on the targeted samples. The crater profile and depths were measured by surface roughness tester and then analyzed. The erosion crater profiles, for the bare substrate and the clad layer, were recorded in diametric direction of the craters and shown fig.4. The erosion crater depths on the bare Ti-6Al-4V sample and clad layer were about 120 μm and 50 μm respectively. It indicates superior erosion resistance property of the coated samples than uncoated Ti-6Al-4V which may be attributed by harder reinforcement particulates present in the coating matrix.

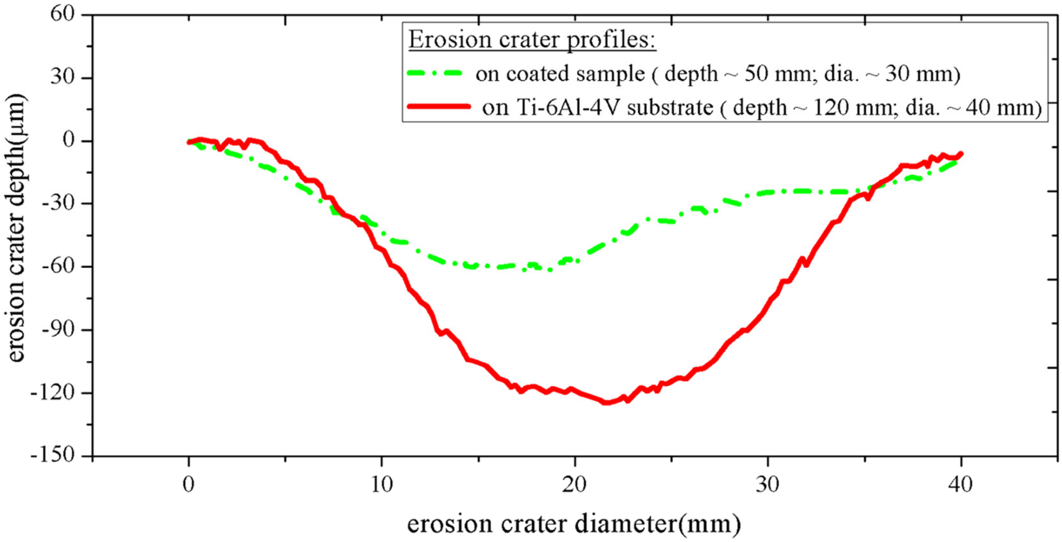



Fig. 4. Erosion crater profile on clad layer and bare Ti-6Al-4V substrate under same condition (as in table 1)

### *2.3. Present status of abrasive jet cleaning/ grit blasting*

Several experiments were conducted on abrasive jet cleaning by different researchers. Some significant works are presented. Griffiths et al. [18] described the on-line monitoring of the grit-blasting process using roughness parameters for plasma spraying. Three types of roughness values were identified and the effects were observed. The centre-line average ($R_a$) value was shown to be the best parameter for on-line condition monitoring. Day et al. [19] conducted an experimental study to understand the effect of grit blasting process using fused $Al_2O_3$ particles on different properties of the substrate and coatings before plasma spraying. Grit sizes (20, 36, 54), blasting duration (4, 6, 8 passes), blasting pressure (20, 35, 50 psi), blasting distance (4, 6 in.), and blasting angle (45°, 90°) were varied to study the effect. They also assessed different properties such as surface roughness, bond strength, specimen distortion and grit contamination and these results were compared with the process variables. Multiple linear regression resulted that the bond strength could be improved by enhancing all the parameters within the given range while the average response method gave indications to the way of modifying the required properties as a function of process variables. A survey on the effect of grit-blasting variables on surface roughness and level of contamination for different alloys was presented by Wigren [20]. It was observed that surface roughness would be maximum where the level of contamination increased rapidly. They also studied the grit-blasting variables for the stickiness of a plasma-sprayed Co-Mo-Cr-Si alloy on Inconel 718. On the other hand, Griffiths et al. [21] described the mechanism of adhesion of sprayed alumina particles on the grit-blasted surfaces. A series of surfaces had been prepared in which the alumina was built up to full coverage. The proportion of splash was identified for high and low adhesion samples in the valleys. Amada et al. [22] conducted experiments to study the influence of grit blasting on the adhesive strength of plasma sprayed coatings. The structural mild steel specimen was roughened by angled grit blasting to enhance the adhesiveness of the coating. Adhesive strength was observed to be maximum at a blasting angle of 75°. Average surface roughness of the roughened substrate was measured with respect to the grit blasting angle, and it was found that the surface roughness was almost the same for different blasting angles. Mohammadi et al. [23] examined the effect of grit blasting parameters on the surface roughness of Ti-6Al-4V alloy for plasma-sprayed hydroxyapatite (HA) coatings using the factorial and Taguchi designs of experiments. In that study, two types of grit materials ($Al_2O_3$ and $SiO_2$), each of two sizes and two types of blasting systems (pressure and suction), were used. Results showed that with an increase in the crystallinity of the coating at the interface, the bonding strength of the coatings reduced. Bahbou et al. [24] reported the effects of grit-blasting and plasma spraying angles on the adhesion strength of Tribaloy 800 that was plasma sprayed on a titanium-base alloy. The study showed that adhesion strength is maximum at 90° blasting and spraying angle while the grit residue becomes maximum at 75° blasting angle. The effect of abrasive grit blasting on the oxidation characteristics of a platinum-modified nickel-aluminide bond coating was analysed by Tolpygo et al. [25]. The analysis revealed that the pretreatment lead to contamination of bond coat by various impurities like alkali, alkaline-earth metals and titanium. They showed that the grit blasting resulted into the increase of oxidation rate and extensive scale spallation during cyclic oxidation at 1150°C. Tyagi [26] demonstrated a theoretical model based on the principle of velocity shear instability generated by thermionic process. The output parameters like erosion rate and MRR were controlled by controlling the input parameters, such as magnetic field, electric field, etc. Results indicated that input parameters had significant effect on erosion and MRR.

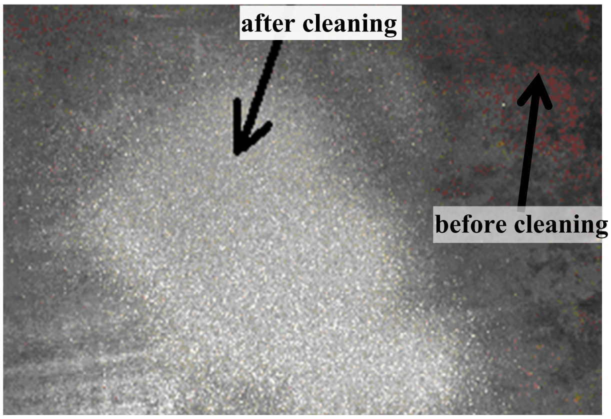



Fig. 5. Rust cleaning from high speed steel surface

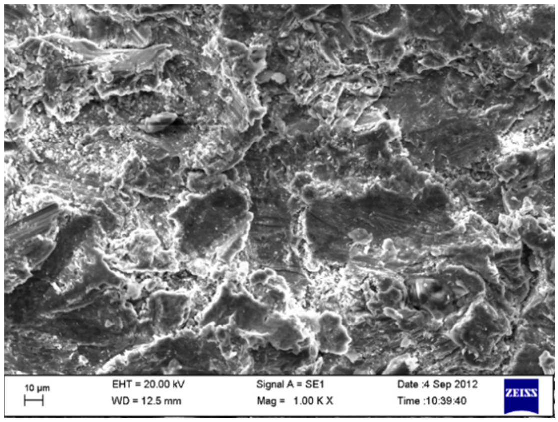



Fig. 6. Surface (topography) preparation using grit blasting for laser cladding

## *2.4. Present status of shot-peening*

Umemoto et al. [27] explored the formation of nanocrystaline structure on a silicon steel (Fe-3.29Si) and eutectoid carbon steel (Fe-0.80C) surface by air blast shot peening process and also by a particle impact technique. The nanocrystaline layers having extremely high hardness were produced. It was also suggested that the necessary condition for producing nanocrystaline structure would be large strain, and the favourable conditions would be high strain and low temperature. Byrne et al. [28] carried out experiments to compare shot peening process with abrasive blasting processes on the basis of deposition of hydroxyapatite coatings on titanium alloy (Ti-6Al-4V). Shot peening process produced a smooth layer of apatite while the jet of hydroxyapatite and abrasive particles resulted in an increase in mechanical bonding of hydroxyapatite into the metal surface. Higher adhesion was observed because of the mechano-chemical bond between the hydroxyapatite and titanium substrate.

By using small balls (steel or ceramics) and changing the nozzle shape, shot-peening operations can be conducted in the present set-up.

## 3. Conclusion

As per search and review, abrasive jet system is rarely designed and manufactured homely for technology transfer. It is evident that one single set-up can be utilized for typical and essential experimental investigations like machining, erosion testing, shot peening, fast cleaning, surface preparation, etc. essential operations.

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