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Fine finishing of internal surfaces using elastic abrasives

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ABSTRACT

The paper describes a simple and innovative approach of using elastic abrasives for generating ultra fine finish on internal surfaces of tubular specimens. Elastic abrasive is a unique concept of using abrasive embedded elastomeric balls having the special capability to deform in conformity to work surface and thereby imparting a very fine refinement of its profile without altering the form. The mechanism of material removal in the proposed methodology is analysed using a mathematical model and its validation was done using a systematic experimentation procedure. Response surface methodology using central composite design is applied for the experimental study to investigate the effect of axial pressure, abrasive grain size and longitudinal stroke velocity of elastic abrasives on the surface finish. The process discussed in this paper is a simple and cost effective option to produce micro/nano-finish on the internal surfaces of a wide range of industrial components including hollow specimens, high aspect ratio bores and sleeves.

1. Introduction

Ultra fine finish on internal surfaces of tubular work pieces and high aspect ratio bores are reported to be achieved by various forms of free abrasive finishing techniques. Abrasive Flow Finishing (AFF) using a self deformable and visco-plastic medium is a promising approach identified for fine finishing of intricate internal surfaces and holes [1,2]. The selection of appropriate tooling and proper carrier medium are the important criteria in this methodology. Magnetic Abrasive Finishing (MAF) is another mode of abrasive application investigated by many researchers [2,3], for finishing the internal surfaces of cylindrical work pieces. Studies on magnetic abrasive finishing by Shinmura et al. [4,5], development of magnetic abrasive jet machining by Kim et al. [6] are typical examples. Wang and Hu [7] studied the inner surface finishing of aluminium, brass and stainless steel tubes using MAF approach. The experimental studies indicated that the characteristics of magnetic abrasives and the control of magnetic field are critical requirements in this method. Studies on internal polishing of thin and long stainless steel tubes and alumina ceramic components using magnetic assistance are reported by Wang et al. [8] and Yamaguchi and Shinmura [9], respectively. Yamaguchi also reported the development of a typical internal polishing process by applying magnetic abrasives using a pole rotation system [10]. Magneto Rheological Abrasive Flow Finishing (MRAFF) and magneto rheological jet finishing are typical advanced strategies reported in this category for nanoscale finishing of external and internal surfaces, which use a field responsive smart fluid for carrying the abrasives [2,3,11,12]. The concept of centrifugal force assisted abrasive flow finishing projected by Walia et al. [13], investigated a hybrid approach by introducing centrifugal force to the abrasive media by rotating a centrally placed rod inside the hollow workpiece. This approach is reported to be effective for the polishing of hollow work pieces. But special fixtures and tooling arrangement are the key requirements for this technique [2]. The application of erosion principle was also investigated through Fluidized Bed assisted Abrasive Jet machining (FB-AJM), for the internal polishing of aluminium, stainless steel and inconel tubes [14,15]. This technology uses the fluidized bed hydrodynamic to feed the abrasives uniformly inside the hollow workpiece and an average roughness value of the order of 0.1 μm is reported on the finished surfaces.

In this paper, a new approach of using 'elastic abrasives' for fine finishing of internal surfaces such as tubular work specimens, hollow work pieces and high aspect ratio bores is proposed. The basic idea is to use elastomeric polymer beads embedded with abrasive grits moving inside the work specimen to remove very small quantity of material to get nano-level surface finish. The size of the polymer beads is preferred to be in the meso/micro-range depending on the dimension of work specimen. Resilience is one of the major mechanical properties that led to the choice of elastomers for the proposed application. An elastomeric polymer will exhibit viscoelastic behaviour with low Young's modulus and relatively higher resilience, allowing the base media to absorb energy when it is deformed elastically and recover it upon

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unloading. The proposed elastic abrasives are having the flexibility to deform itself in conformity to the shape of work surface. This elastic deformation and higher contact area will lead to lesser contact pressure resulting in lower penetration depth during the abrasion, in comparison with a normal rigid abrasive grit. Because of the fine penetration and the flexibility to deform in conformity to the work surface, the proposed embedded particles are having the most significant advantage of finishing the surfaces without altering its form.

2. Formulation of elastic abrasives

In the present work, special grade polymer beads of average size 3 mm is used as the elastomeric medium. The selected polymer is having the following specific characteristics.

- The polymer is highly resilient.
- Surface softening can be easily achieved on the polymer using an appropriate chemical reaction.
- The polymer is having a reasonably high temperature stability to avoid the fusing of beads during the process.

In the present study, a direct chemical approach was followed to develop the elastic abrasives, in which fine grits of abrasives were embedded on the polymer beads. The polymer beads were mixed with abrasive grits using the chemical solvent at an appropriate temperature to form the elastic abrasives. During the process, the size of the particle can be controlled by different means, one being the selection of an appropriate sized polymer bead. Using this methodology, fine abrasives can be embedded effectively on the elastomeric polymer beads to make 'elastic abrasive particles' of average size 3 mm as shown in Fig. 1.

3. The design and development of experimental setup

To investigate the proposed approach of using elastic abrasives for the generation of fine finished internal surfaces in tubular work pieces, a specially designed experimental setup was developed. The setup mainly consists of a pneumatically powered cylinder-piston arrangement to guide the elastic abrasives inside the hollow work piece. There are two double acting cylinders positioned on either side of a rigid base plate as shown in Fig. 2. The tubular work specimen is located at the centre of the base plate

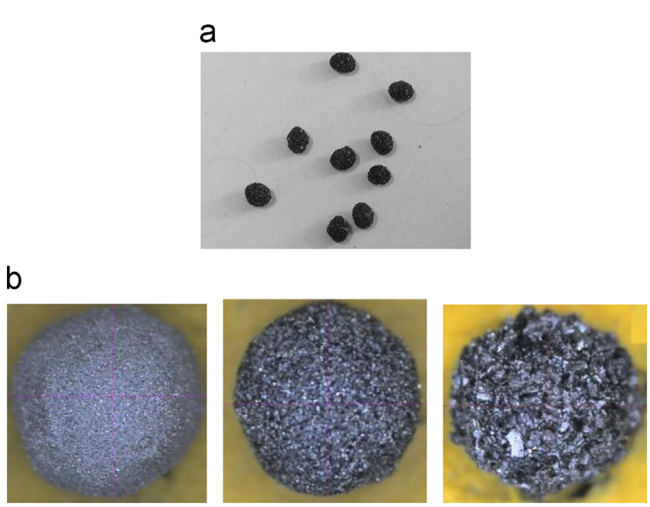

Fig. 1. The microscopic views of elastic abrasive particles [33 X]. (a) Developed elastic abrasives. (b) Elastic Abrasives with 10 μm, 130 μm and 250 μm embedded grains.

with two guide bushes on either side of it. The piston rods were attached to the extension rods using flexible coupling, allowing the rods to pass through the guide bushes and the work piece during the stroke. Flexible couplings with elastic padding are used to ensure proper alignment of the rods. Sufficient clearance is given between the extension rod and the internal surface of work piece, to facilitate smooth movement of rods inside the specimen, without rubbing the surfaces. The extension rods were guided using two guide bushes, maintaining a close clearance fit. The movement of the pistons are controlled using a two position 5 port 4 way spring return directional control valve actuated by a solenoid. The circuit is designed in such a way that the pistons are to move in the same direction. The solenoid is triggered using a microprocessor controlled relay circuit with an adjustable cycle time. Various longitudinal velocities were achieved for the piston at a particular pressure by programming the microprocessor.

4. The proposed experimental methodology

After filling the tubular work specimen (almost 75% of the inner volume) with elastic abrasives, the extension rods on both sides are aligned using the guide bushes. Since the designed circuit will allow the pistons to move only in the same direction, one piston will be in its extreme backward positions as the second one is at the extreme forward position. In the present setup, the gap between the rods at this extreme condition is restricted to one-fourth of the specimen length (almost 12.5 mm). As the pneumatic supply is given, the pistons will come to the extreme position, axially squeezing the elastic abrasives. The gap between the rods at the extreme position is an important factor deciding the longitudinal compression. As the piston is reciprocated using the pneumatic supply, the axially compressed elastic abrasives will move to and fro inside the hollow surface. Appropriate length of guide bushes should be chosen such that the extension rods will be always located inside the bush during the reciprocation, even at the extreme backward position of the piston, ensuring that the particles will not come out of the specimen.

5. Theoretical analysis of material removal

5.1. The mechanism of material removal

The mechanism of material removal in this methodology is typically the abrasion and micro cutting by the embedded abrasive grits. As shown in Fig. 3(a and b), the axial squeezing of the elastic abrasives by the pistons will be the first action during the process. When the solenoid actuated directional control valve starts its function, the pistons in the double acting cylinder will impart to and fro linear strokes to the packed elastic abrasive balls. During the axial compression of elastic abrasives, it will tend to deform in the radial (lateral) direction because of the presence of soft elastomeric polymer. The radial deformation will press the particle against the work surface at the contact interface (particle-work surface contact zone), whereas the deformation in the non-contact zone will be constricted by the firm packing of elastic abrasives. The highly resilient elastomeric medium will allow the elastic abrasive balls to deform in conformity to the work surface at the interface regime as shown in Fig. 3(c). This deformation results in more number of active grains coming into contact with the surface to be finished. The embedded abrasive grains in the contact area will penetrate into the work surface due to the radial force. The polymer core will act like a spring, absorbing the energy during the penetration of particle, resulting in a finer depth of penetration compared to a regular abrasive grit under the action of same