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WATER JET PEENING - A NEW SURFACE TREATMENT PROCESS

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Abstract: Water jet peening is a novel surface treatment process that is gaining importance over the past two decades. In contrast to shot peening, water jet peening offers several benefits such as improved fatigue strength and resistance to corrosion, simplicity of process control due to less number of variables influencing the process and highly flexible in terms of treating inaccessible and critical areas. As this process makes use of water for enhancing the compressive residual stresses in the surface layers, it is a potential surface treatment process for treating different types of materials. This paper provides an overview of the work done in this particular area of considerable importance to material scientists and researchers.

Keywords: Peening, residual stress, water jets.

1. Introduction

Applications of water jets range from cleaning to cutting in different fields like construction, maintenance and manufacturing industries. Among the different applications of water jets, water jet peening is a novel surface treatment process that is gaining momentum in the recent past due to certain unique characteristics. It is a force-controlled treatment that generates compressive residual stresses in the surface layers without modifying the surface topography. It is relatively easy to control due to less number of variables affecting the process. This process is capable of treating the entire surface uniformly thus requiring simplified quality assurance procedures. Above all, it is capable of treating surfaces with complex geometries and having certain inaccessible areas. Over shot peening, it offers several benefits such as improved fatigue strength and resistance to corrosion, highly flexible process that can simultaneously be used along with other material removal processes possible with high-pressure water jets. Unlike shot peening, water jet peening is an environmental friendly process since it does not produce any dust during the surface treatment of materials.

Salko [8] made an attempt to investigate experimentally the water jet peening process. Investigations revealed that the water jet peening enhanced the fatigue life of materials due to an increased crack initiation life and reduced crack propagation life. Further, the surface produced by water jet peening is exceedingly smooth thus not requiring any post finishing operations. Though a few attempts were made to perform water-peening experiments in under water, most of the researchers performed investigations only in air. Under water peening was especially employed to prevent stress corrosion cracking and fatigue fracturing of materials used for underwater applications.

In water jet peening, several parameters such as nozzle geometry, water jet pressure, stand off distance and peening duration influence the process results. Different geometries that were employed for water jet peening include round nozzles, conical nozzles, flat nozzles and

Abrasive Water Jet (AWJ) cutting nozzles. Experimental studies with different nozzles indicated better results with flat nozzles due to uniform distribution of droplets that impart uniform pressure on the surface. Most of the water peening studies employed low pressures of water in the range of 20 MPa to 140 MPa for treating materials like aluminium alloys, tempered steel, case hardened steel and stainless steel. Recent attempts cover high-pressure water jet peening employing water pressure of 400 MPa by using round nozzles. Unlike shot peening process, water jet peening process is governed by the velocity of jet i.e. the velocity of water droplets is impinging the material surface. In contrast to shot peening, this process is less expensive since shot peening requires substantial investment on the shot material whose cost depends on the size, shape, density, hardness, yield strength and modulus of elasticity of shots used. Though several attempts demonstrate the benefits of water jet peening over shot peening, this process is still at its infancy in terms of its application for treating a variety of materials and its widespread use in industry.

This paper reviews the efforts made by several researchers in this potentially important process for treating different types of materials with different types of surfaces. First, it looks at the mechanism of water jet peening, structure of jet that is responsible for causing changes to the surface treated with water, and different parameters that affect the process results. Then, it covers the attempts made to characterize the water-peened surfaces. Apart from this, it also includes some details on different types of nozzles employed for water jet peening and discussion on the results of water jet peening.

2. Mechanism of water jet peening

The mechanism of water jet peening is essentially due to an impingement of droplets of water on the surface. These droplets generate a surface pressure distribution producing peak loads that exceed the yield strength of the material. These peak loads induce localized plastic deformation, which is constrained by the surrounding material thus inducing high compressive residual stresses on the surface. As the droplets of jet are responsible for generating high compressive residual stresses on the water peened surfaces, it is essential to identify the droplet region in the structure of jet and then to employ this region for treating the surfaces with water jets. Hence, the following section deals with the structure of water jets in air.

3. Structure of water jet in air

Figure 1 shows the structure of water jet in air with increasing distance from the nozzle. It consists of three different regions, each with substantially different jet characteristics. In the initial region that exists just below the nozzle, the jet has continuous flow characteristics. When the work surface is located in this region, the jet generates constant axial dynamic pressure with peak loads far below the yield strength of the material. Hence, this region is not suitable for water peening since it does not cause any plastic deformation in the material.

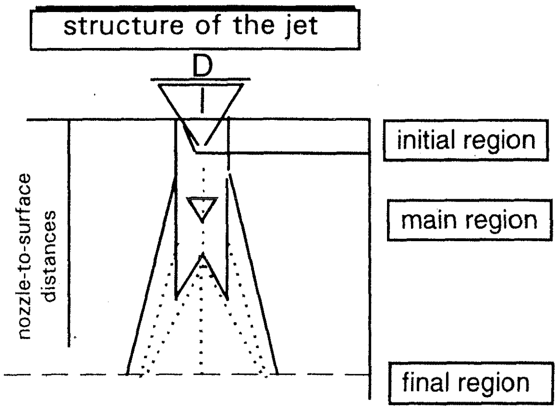


Fig. 1. Structure of water jet in air [6]

The initial region is followed by main region where the continuous water jet disintegrates into droplets. The impact of these droplets causes peak loads, which in turn induce local plastic deformation on the surface at the spot of impact. As described earlier, this particular phenomenon is responsible for enhancing the compressive residual stresses on the surface. The third region, known as diffuse region, follows the main region. In this region, the droplets are scattered over a larger area. Hence, this region again is not useful for surface hardening. Thus, it is very important to locate the work surface in the droplet region for water peening of surfaces. As this droplet region depends on several process parameters such as jet pressure, nozzle geometry and peening duration, it is necessary to understand the influence of these parameters in water jet peening.

4. Influence of process parameters in water jet peening

Different process parameters such as nozzle geometry, jet pressure, nozzle to surface distance, peening angle and peening duration influence the results obtained with water jet peening. In Fig. 2, the parameters that influence the water jet peening are shown. For any given set of conditions such as jet pressure, nozzle to surface distance and peening angle, peening duration is the one that can affect the process significantly. It can be estimated by using the relation

$$t_s = a / V_f$$

where t_s is the peening duration, a is the width of the water jet and V_f is the nozzle feed speed.

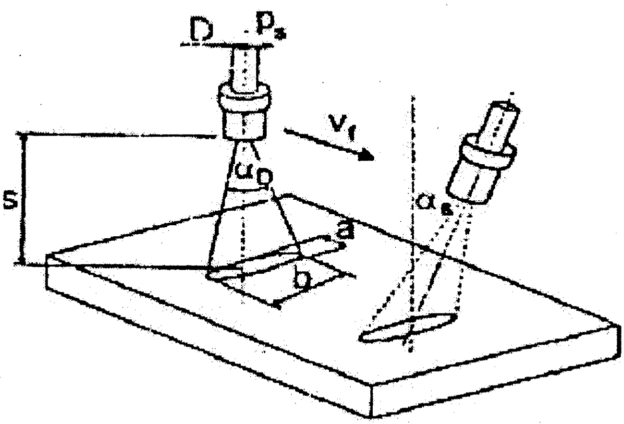
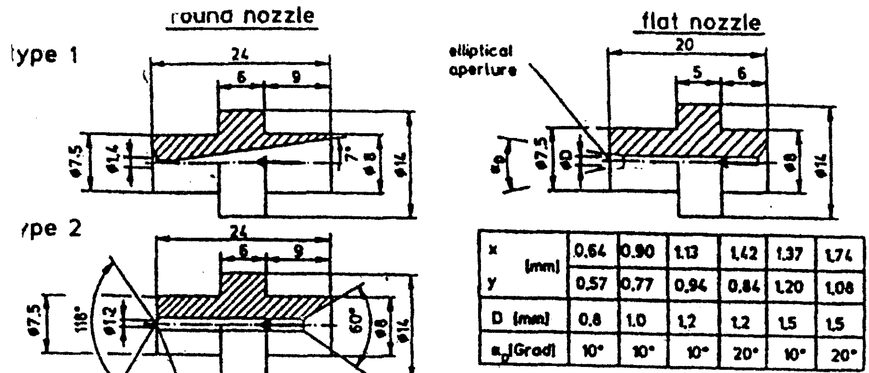


Fig. 2. Different Process parameters influencing water jet peening [6].

Figure 3 presents the different geometries of nozzles such as round nozzles, flat nozzles, and AWJ cutting nozzles employed for water jet peening [5]. Among the different geometries, the round nozzle with a conical bore and cylindrical bore were used to study the influence of different jet characteristics on case hardened steel specimens treated with water jets. A peening duration in the range of 5s to 15s and the pressure of 75 MPa were employed for this purpose [2,5]. In case of round nozzles with a conical bore (type 1), the maximum compressive residual stress level increased from −350 MPa to −

500 MPa for a nozzle diameter of 1.4 mm. In case of round nozzles with a cylindrical bore, these stress level increased from –400 MPa to –550 MPa for a nozzle diameter of 1.2 mm.



x (mm)	0.64	0.90	1.13	1.42	1.37	1.74
y (mm)	0.57	0.77	0.94	0.84	1.20	1.08
D (mm)	0.8	1.0	1.2	1.2	1.5	1.5
α_D (Grad)	10°	10°	10°	20°	10°	20°

Fig. 3 Different types of nozzles employed for water peening [5]

In case of flat nozzles, the exit aperture is elliptical in nature. Due to this, the jet is wider and spread out with nozzle angles of 10° and 20°. It produced a rectangular or elliptical cross section of the jet on the surface of the work piece. Investigations were carried out on case hardened steel specimens using flat nozzles, with a spread angle of 20° and nozzle to surface distances in the range of 30 mm to 70 mm. The maximum compressive residual stresses of more than –500 MPa were noticed on the surface when the pressure of 75 MPa and a peening duration of 0.5s were employed [2]. Ramulu et al. used AWJ cutting nozzles for peening 7075-T6 aluminum alloys by varying the stand off distance from 13 to 152 mm and pressures in the range of 60 MPa – 140 MPa. The magnitude of compressive residual stresses induced at a subsurface depth of 50 microns is about 15 percent higher than that in the base material hardness. Among the above nozzles, the flat nozzles were found to be more efficient in view of higher compressive residual stresses induced in the peened surface.

5. Characteristics of water peened surfaces

In water jet peening, different parameters such as hardness, residual stresses, surface topography and fatigue strength were employed to characterize the surface treated. The hardness and residual stresses on the surface treated with water jets in aluminum alloys and case hardened steel specimens were measured [2,5,8]. Ramulu et al. assessed the variation in surface hardness using Vickers hardness measurements on aluminum alloy 7075-T6. By using X-ray diffraction method, residual stresses and peak diffraction width were measured before and after water jet peening. These studies indicated compressive residual stresses in the range of -20 MPa to -45 MPa when the surfaces were treated with water jets employing jet pressures in the range of 60 –140 MPa and stand off distance in the range of 36-45 mm. Toenshoff et al. [2] investigated the surface treated with water jet and noticed that the compressive residual stresses of -500 MPa were obtained when the peening duration was varied between 0.5sec to 5secs, and with nozzle to surface distance of 40 mm and water jet pressure of 75 MPa.

Experiments were conducted on 1100-H14 aluminum specimens by employing stand off distances in the range of 80 mm to 150 mm and water pressures of 100 MPa and 140 MPa. Various parameters such as surface roughness, hardness and residual stresses were measured [8]. High pressures in the range of 200 MPa to 500 MPa were employed to treat 304 stainless steel plates with water jets [3]. By using X-ray diffraction method, compressive residual stresses on the surface were measured. In order to find out the depth, to which the water jets can affect the materials, the distribution of residual stress in the subsurface was measured by removing the surface layers using etching technique upto a depth of 250 μm [3].

An increase in fatigue strength is attributed to an increase in compressive residual stresses and hardness in the surface layers. Several investigations were conducted to increase fatigue strength of peened components such as case hardened steel and tempered steel specimen [5]. To evaluate the improvement in fatigue strength of materials, the rotating bending tests were carried out using notched specimen [5]. Results clearly showed an improvement in the fatigue strength of notched specimen to an extent of 31 percent over that obtain with the specimen not treated with water jets. Thus, the above investigations clearly indicated the effectiveness of water jet peening for treating certain materials. However, this particular field requires detailed investigations in order to assess its suitability for a range of materials with different surface conditions.

6. Summary

From the review of literature, it is found that only a few attempts are made to investigate the applications of water jets for peening applications. Different nozzle geometries were used for treating only a few materials like case hardened steel and tempered steel specimens with low pressures. Flat nozzles were found to be suitable for treating peening specimens with water jets effectively Studies showed the possibility of using AWJ cutting nozzles for treating materials employing jet pressures both lower and higher ranges. As these investigations are limited to peening only a few materials, there is enough scope to investigate this process further to apply it for treating a variety of materials in manufacturing.

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