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ScienceDirect
Procedia Engineering 149 (2016) 472 – 480
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Manufacturing Engineering and Materials, ICMEM 2016, 6-10 June 2016, Nový Smokovec, Slovakia

Potential of using water jet peening as a surface treatment process for welded joints

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Abstract

Water jet peening is a mechanical surface strengthening process which has gained momentum in the last two decades. It is an application of water jet abrasion process which improves the residual stresses of the treated surface. In comparison to other conventional methods like shot peening, laser shock peening water jet peening offers resistance to corrosion, improved fatigue resistance, simpler control over the process, full coverage of the treated area, flexibility in treating complex areas and eco-friendly environment. Since WJP uses water for improving the residual stresses it is a potential method for treating a variety of materials. The high pressure water jets has the tendency to cause the surface damage if the parameters are not maintained within optimum conditions therefore, optimum conditions must be determined so that surface treatment can be carried out without causing any detrimental effects. Hence, it is necessary to control the peening parameters which are: Jet pressure, Standoff distance, nozzle geometry, nozzle traverse rate and exposure time.The paper aims at reviewing the work contribution for using Water jet peening as a potential surface treatment process.

Peer-review under responsibility of the organizing committee of ICMEM 2016

Keywords: "Water jet;Peening;Residual Stress."

1. Introduction

The wide application of welded structures in power plants, industrial machines, transportation vehicles etc. requires ensuring its integrity against the fatigue and corrosion for the longer usage. The fatigue strength of a component is mainly affected by the factors like residual stress, stress concentration, macro and micro structure and mechanical properties of the material [1]. Out of these residual stress is one of the significant factor the effects the working characteristics of the welded joints. In the past few decades welding residual stresses has been investigated and gained much attention due to its adverse effect on the welded components like stress corrosion cracking, fatigue and creep life of the component etc [2][3][4][5]. To maintain the quality of these welded components it is necessary to reduce or control these stresses. Over the years, possible methods have been investigated to attenuate their effect. An effective way to reduce these stresses is to introduce compressive stress on the surface which tends to increase the fatigue resistance and resistance to stress corrosion cracking [6] [7].

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Peer-review under responsibility of the organizing committee of ICMEM 2016
doi:10.1016/j.proeng.2016.06.694

Nomenclature

WJ	Water jet
WJP	Water jet Peening
AWJ	Abrasive water jet
PWJ	Pulsating water jet
SOD	Standoff distance

The treatment of the welded components is important to enhance the performance of the component. Although, in process control of residual stresses during welding is easier to apply than post welding treatment but the post weld treatments have confirmed the improvement in the residual stress on the surface and the tolerance against both fatigue and stress corrosion cracking[1]. Various mechanical treatment processes has been employed to improve the surface characteristics. The compressive stresses in ductile materials are induced mechanically by localized plastic deformation within outer surface region. In today's industry these mechanical surface treatment process has divided into cutting and non cutting methods. The primary objective the cutting methods are to shape the product and its secondary objective is to achieve optimal surface layer. In contrast to this the non cutting methods primarily enhances the surface layers condition [8]. These surface treatment processes have been used for a wide range of materials from semiconductors to metals, ceramics, polymers, bio and nonmaterial's. Few of the common methods used to introduce the compressive stress on the surface are shot peening, laser shock peening [9]. Shot peening process involves the bombardment of spherical shots made up of hardened cast steel, glass or ceramics beads at high velocity on the part surface. The possible disadvantages associated with the process include defects and rough peened surface which has pernicious effects to fatigue crack initiation [10]. In contrast to this, the laser shock peening process involves the formation of high pressure shock pulses by a high intensity laser for duration of nanosecond pulse at the surface of the material [11]. The short pulses of the high intensity laser alter the material property by inducing tamped plasmas at the point of impingement. This plasma produces high amplitude shock waves at the surface which propagates into the interior of the target material that subsequently induces residual stresses [11]. There are also the possibilities of thermal effects such as melting of metal surface especially for alloys having low melting point [12].

In the recent years a new technology Water jet peening is being used to introduce compressive stresses in the surface. It is a novel method of surface strengthening process with negligible influence on the surface roughness and surface texture. WJP process involves a continual impact of high velocity water jet that impinges on the surface of the component. The impact of water jet causes local plastic deformation and generates compressive stress in the surface and near layers of the workpiece [13]. This leads to the enhancement of surface hardness and fatigue life. This technique is being used as preventive maintenance technique in nuclear power plants**.**WJP is characterized by following advantages as compared to the conventional treatment methods:

- Workpiece with complex geometries and kerfs of high notch acuity can be treated by water peening
- Complete coverage of surface is guaranteed
- Investigations proved no change in roughness after water peening.
- Small no. of process parameters and const. Quality of water simplify process control.
- Low costs for the preparation of the water are an economical advantage compared to shot peening.
- Environmental friendly process because it does not produce dust. [14]

The present work focuses on reviewing the applicability of using water jet peening as a surface treatment process for different materials. Firstly the mechanism of water jet peening process, structure of the jet that is responsible for improving residual stress of the treated surface is explained then the effect of different process parameters that helps in mitigating the adverse effects of the residual stresses is discussed. Further, the future modifications in this technique to obtain better results are discussed.

2. Mechanism of WJ

The mechanism of Water jet peening occurs due to the impingement of the water droplet on the treated surface. The high pressure water injecting through the nozzle is impacted on the surface of the material to be treated. This impact of high pressure water jet generates cavitations which collapses after a moment and generates intensive pressure wave. The surface pressure generated produces a peak load that exceeds the yield strength of the material and induces localized plastic deformation which is constrained by the surrounding material as a result high compressive residual stress is developed on the surface.[15]

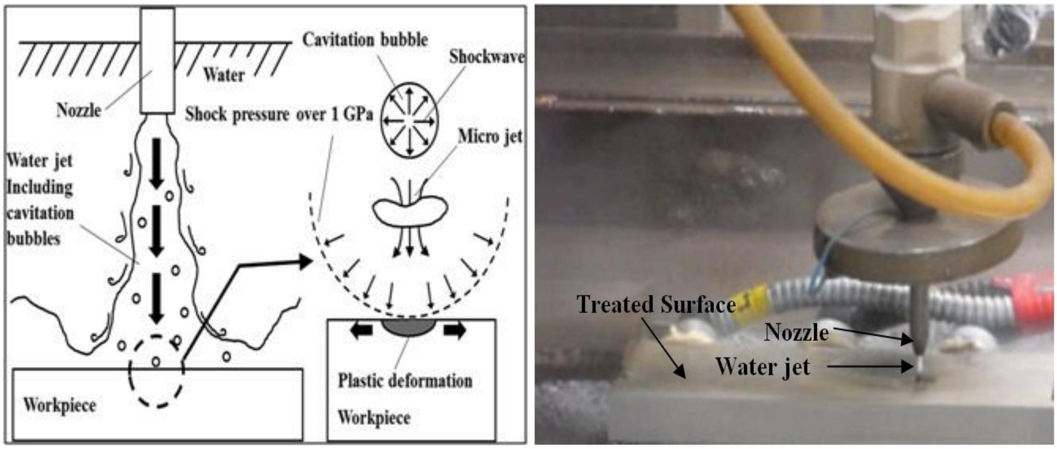


Fig.1. (a) Mechanism of residual stress improvement with WJP [29] (b) Experimental Setup of WJ [27]

The generation of the high compressive residual stress is dependent on the formation of the droplets of the jet. Therefore it is essential to identify the region of the droplet formation in the structure of the jet and employing this region for treating the surface [15]. The structure of a jet(fig.2) exiting the nozzle can be divided into three regions: a) Initial Region-when the workpiece is placed in this region the jet is generated with constant axial dynamic pressure having peak loads below the yield strength of the material. Therefore the region is not suitable for the WJP as no plastic deformation occurs. b) Main or transition region-Impact of droplets in this region causes peak loads which induces plastic deformation in the region of impact. c) Final region-The droplets in this region scatter over larger region which is not useful for surface treatment process [15](fig.3). Thus, it is essential to locate the work surface in the main region for the WJP of the surfaces [15].

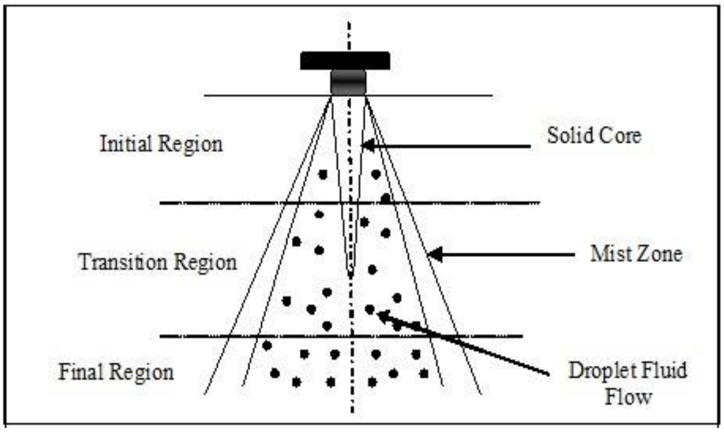


Fig.2. Change in jet structure with distance from nozzle [18]

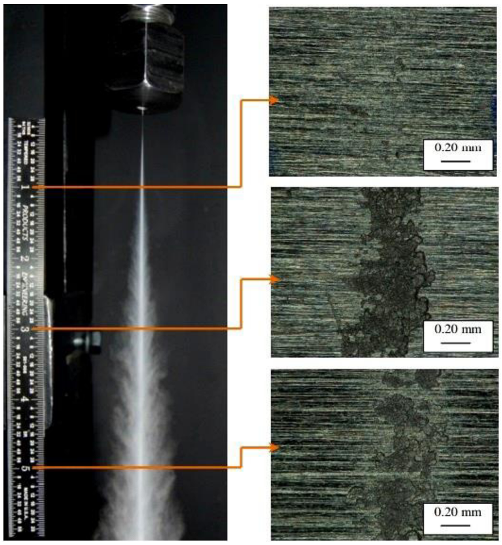
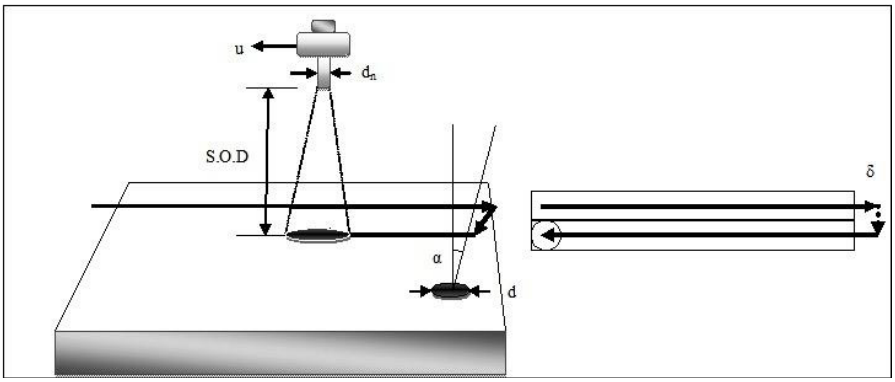


Fig.3 Water jet processed titanium surfaces showing degree of erosion relative to the highlighted standoff distance.
Jet conditions: P = 414 MPa; u = 30 mm/s; dn = 0.254 mm. (Scale in inches).[18]

3. Influence of Process Parameters

The high pressure water jets has the tendency to cause the surface damage, therefore, optimum conditions must be determined so that surface treatment can be carried out without causing any detrimental effects. Various aspects of input parameters such as hydraulic pressure , abrasive properties, nozzle geometry , machine parameters and the properties of the target material effects the quality of the treated surface[17].Parameters like jet velocity , nozzle geometry, the angle of attack of the jet influence the coherence as well as cutting power. However, SOD and traverse speed of the nozzle are the main parameters that affect the interaction between the jet and workpiece surfaces. To achieve the optimum levels of the significant parameters it is essential to conduct a design of experiment. DoE is a methodical technique that determines the relationship between the independent variables of the process and dependent variables of the process or it is a series of tests in which the input factors are purposefully changed so as to observe and identify the reasons behind the change in the output variable. It involves the methodology of finding out the combination of factors which will influence the performance of the process with lowest possible cost and minimum energy consumption. With an aim to acquire as much as information as possible on WJ peening factors in relation to the residual stress hardness and roughness of the treated surface different studies have been conducted. Figure.4(a) represents typical process parameters that are to be optimized: water pressure: P, standoff distance: s.o.d., feed rate: u, peening angle: α, nozzle diameter: $d_{n.}$



(a) (b)

Fig.4. Water jet peening process(a) relevant parameters (b)Sketch of the path traced [17]

3.1. Jet Water Pressure

The jet water pressure has a significant effect on the surface being treated. Various researchers have observed the effect of the water jet pressure during the WJP process. N. Rajesh et al. [17] during the empirical Modelling of Water-jet Peening of 6063-T6 Aluminium alloy observed jet pressure to be the strongest contributing peening parameter in improving the hardness of the treated surface .Similar observations were made by Ramulu et al. [19] while carrying out the water jet peening of metals. It was observed that the erosion resulting from the impingement of the jet were deeper, larger and more severe for the specimens which are subjected to higher pressure. D.Arola et al. [20] investigated the WJ and AWJ surface treatment of Pure Titanium and Titanium alloy and observed that residual stress resulting from WJ peening treatment increases with increase in the jet pressure where the surfaces treated using AWJ decreases with increase in jet pressure (Fig.5).He concluded that the AWJ peening showed better results for the improvement in the residual stress. However, embedment of the abrasive particles on the treated surface has an adverse effect on the fatigue life of the component[21]. While attempting to reduce the Weld Residual Stress by Water Jet Peening in Repair Weld to 304 Stainless Steel Clad Plate Wenchun Jiang et al.[14] concluded that as the maximum impact pressure at the centre of the impact increases the residual stresses decreases and changed to compressive. It was reported after simulating the high pressure water jetting and comparing the stress with and without the application of WJP that when the maximum impact pressure reaches 1.4 times the yield strength of the 304 stainless steel the initial tensile stress reduces to compressive.

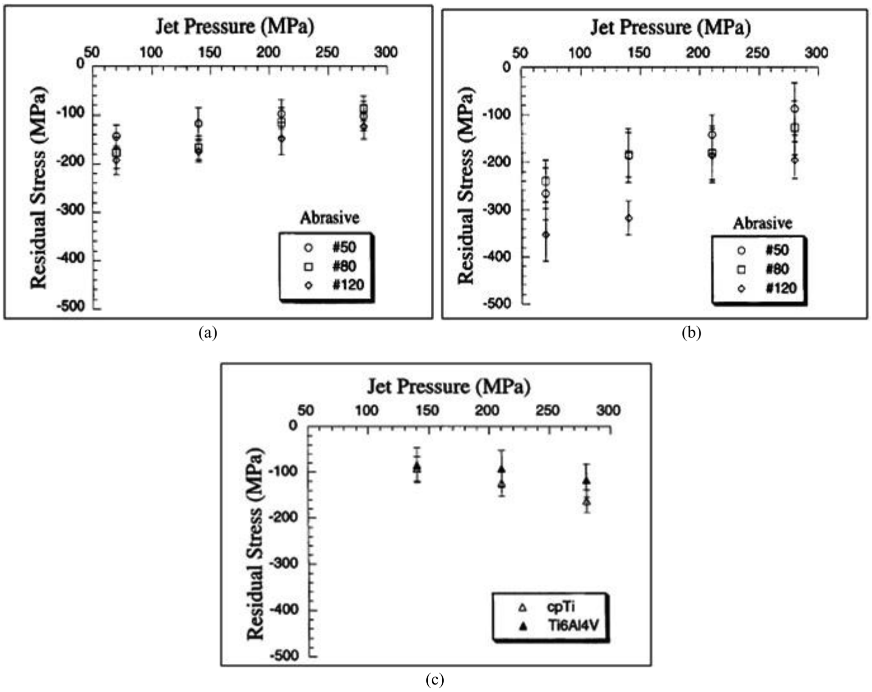


Fig.5. Influence of Jet Pressure on the residual stress. (a) AWJ peening of the CP Ti; (b) AWJ peening of the Ti6Al4V; (c) WJ peening of the CP Ti and Ti6Al4V[20]

3.2 Standoff Distance

Standoff distance highly influences the residual stress formed on the treated surface. Various investigators during their investigation depicted this result. N. Rajesh et al. [17] during the empirical Modelling of Water-jet Peening of 6063-T6 Aluminium alloy concluded that standoff distance contributes about 28% in improving the residual stress of the treated surface. The smaller SOD causes the droplet region to confine to smaller zone with significantly higher droplet velocities thus producing higher residual stresses. M.Ramulu et al. [19] during the WJP of the metals found that the erosion resulting from the jet impingement is narrowest and deepest at minimum SOD. The removal characteristics within the impact zone were found to be predominantly dependent on the SOD. Masahito et al.[13] while studying the residual stress improvement by WJP on the 304 stainless steel weldment observed that when the stress was measured at the centre of the peening line, the residual stress was reduced more than 200MPa on increasing the SOD from 10mm to 40mm.(Fig.6)

PARAMETER	CONDITIONS
1. Angle of the nozzle	90°
2. Hydraulic Pump Pressure	69 MPa
3. Water depth	300mm
4. Repetition of numbers	1
5. X-Ray exposed area	(1*12.5)mm^2
6. Nozzle travelling speed(v)	○ 0.4m/min ● 0.8m/min △ 1.2m/min ▲ 2.0m/min

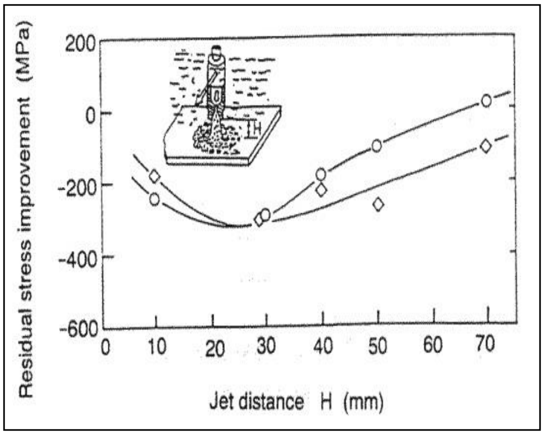


Fig.6. Influence of SOD on residual stress improvement [13]

3.3 Number of Passes

The investigators found that the number of passes has a strong influence in changing the roughness induces on the surface. N.Rajesh et al.[17] while performing WJP process on 6063-T6 Aluminium alloy concluded that at higher standoff distance with a higher number of passes, the jet diverges with lesser droplet velocities at the periphery resulted in less variation of surface roughness. Azhari et al.[22] evaluate the response of austenitic stainless steel 304 subjected to multiple pass treatment during WJP process. It was observed that on increasing the number of passes along with the pressure higher roughness values are achieved with more erosion occurring on the treated surface (Fig.7). The hardness value of the treated surface revealed that higher number of passes along with pressure resulted in greater increase in the hardness of the surface with deeper hardening layer. While exploring the effects of process parameters on the aluminium specimen Azhari et al. [23] observed that the higher number of passes resulted in higher hardness of the treated surface.

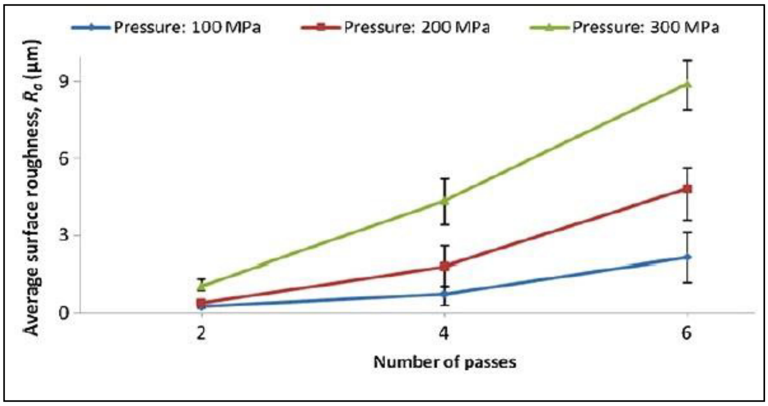


Fig.7. Influence of number of passes and pressure on surface roughness [22]

3.4. Traverse Speed

The traverse speed has shown a reverse relation with the surface roughness in different studies. Azhari et al. [22] during the WJP of austenitic stainless steel observed that rougher surface was produced at lower feed rates because on lowering the feed rates allows more water molecules impingement on the surface thus increasing the roughness of the surface(fig.8). Chillman et al.[24] while analysing the impingement of ultra high pressure water jets on the Titanium surface highlighted two trends: a) as the pressure was increased the erosion rate increased for all traverse rate and b) the maximum attained erosion rate decreased as the traverse rate was increased. However, highest cumulative effect of supply pressure and traverse rate on the erosion rate and roughness parameters.

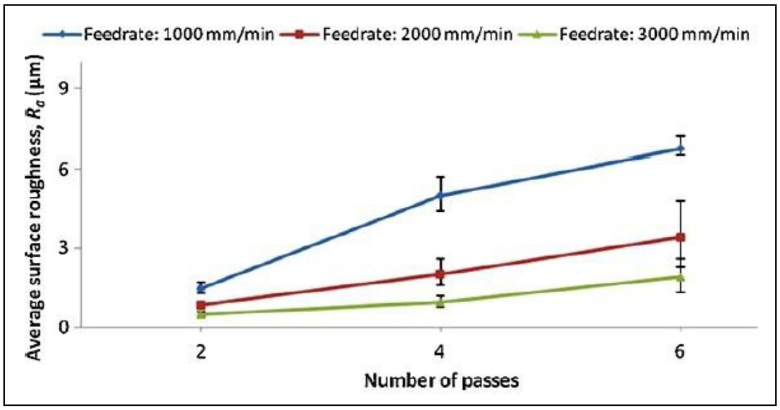


Fig.8. Influence of number of passes and feed rate on surface roughness [22]

3.5. Geometry of nozzle

Previous studies have demonstrated that the nozzle geometry affects the residual stress of the treated surface during the peening process. The different geometries of nozzle i.e. flat nozzles, round nozzles and AWJ cutting nozzles have been employed to study the effect of WJP process on the steel specimens with peening duration 5s to 10s and jet pressure of 75 MPa [25] [26].It was reported that the magnitude of the compressive residual stresses induced at the subsurface depth of 50 microns is about 15%higher than the base material hardness. The results revealed that the flat nozzles were more efficient from the point of view of higher compressive residual stresses induced on the treated surface. [25][26]

3.6 Peening duration

Peening duration is evaluated by the traverse speed of the nozzle and the number of passes. Few studies have also considered the effect of peening duration on the improvement of residual stress. During the study of residual stress improvement using WJP on the 304 Stainless Steel Masahito et al.[13] investigated the effect of peening duration. The peening time greater than 4minutes/meter resulted in the improvement of the residual stress more than 300MPa (Fig.9).

PARAMETER	**CONDITIONS**
1. Jet distance	30mm
2. Angle of the nozzle	90°
2. Hydraulic Pump Pressure	69 MPa
3. Water depth	300mm
4. X-Ray exposed area	(1*12.5)mm^2
5. Nozzle travelling speed(v)	○ 0.4m/min ● 0.8m/min △ 1.2m/min ▲ 2.0m/min

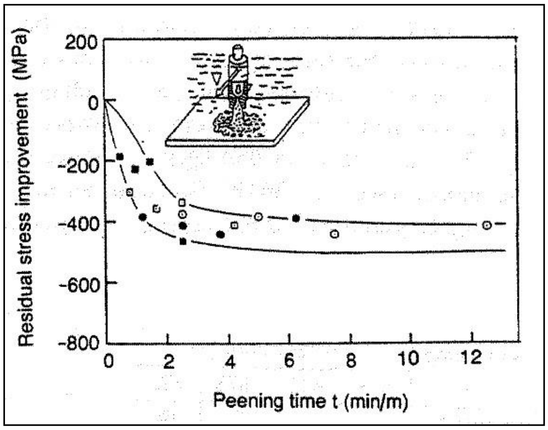


Fig.9. Influence of peening time on residual stress improvement [13]

4. Conclusion

Water jet peening has emerged as a promising technique for mitigating the stress corrosion cracking which results into the improvement of the residual stresses (from tensile to compressive) and the fatigue life of the component. The previous studies have proved WJP as an efficient technique for the surface treatment process for different materials like 304 Stainless Steel, Aluminium alloy, Titanium alloys etc. The ecology and economy of the conventional methods are not all times optimal therefore this unconventional method has gained interest [27].Still there is enough scope to apply this treatment process for variety of materials in manufacturing. The previous investigations have also revealed the application of this technique in some welded joints [1][14]. Mochizuki et al. [1] examined the effectiveness of the Water Jet Peening of butt welded austenitic stainless steel joint. The test showed that Water jet peening technique prevents Stress corrosion cracks in welded Joints as no cracks was observed in the region that was treated with water jet (fig.10). The previously analyzed data have to be further processes, filtered and interpreted perfectly and professionally [28]. From the previous studies it can be concluded that:

i) WJP is an effective technique to prevent stress corrosion cracking and fatigue fracturing in the component. [13]

ii) For the efficient use of this technique peening parameters i.e. jet pressure, peening time, number of passes, nozzle geometry and standoff distance must be controlled. [13]

iii) WJP process under controlled parameters is suitable for shop floor application. [17]

iv) It has potential to be used as preventive maintenance technique in nuclear power plants. [13]

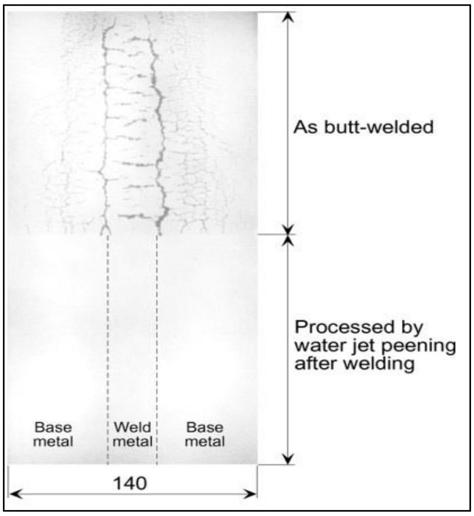


Fig.10. Result of SCC test in a plate-welded butt-joint with and without water jet peening treatment [1].

5. Future Scope

The advancements in the field of WJ allow a continuous waterjet to modify into abrasive and pulsating waterjet. The application of WJ and AWJ at high pressure has some technological and economic limits. Currently, the technology is trending towards the erosion of materials at lower pressures for which pulsating WJ is the solution. In the Pulsating water jet the effectiveness of the jet is improved by the generation of pulses. The jet exiting from the nozzle is initially continuous but later breaks into individual clusters of the fluid [30]. So the application of pulsating waterjet peening for the surface treatment process for the welded joints can give a new direction to this technique. By investigating the effects of different process parameters on the residual stress and hardness of the welded component optimum range of parameters can be determined in which the process is highly efficient to prevent stress corrosion cracking and improve fatigue life of the component.

Acknowledgement

This work was supported by the Slovak Research and Development Agency under Contract No. APVV-207-12. Experiments were carried out with the support of the Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use - Sustainability Program, reg. no. LO1406 financed by Ministry of Education, Youth and Sports of the Czech Republic, and with support for the long-term conceptual development of the research institution RVO: 68145535.

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