EXPERIMENTAL INVESTIGATION ON WATER JET PEENED 316L STAINLESS STEEL WELD PLATES

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ABSTRACT*: Austenitic 316L Stainless Steel are TIG (Tungsten Inert Gas) welded and are water jet peened by varying two main parameters - pressure and stand-off distance. This induces compressive residual stresses by local plastic deformation. The residual stresses of samples before and after water jet peening are measured using XRD. TIG welded samples show residual tensile stress and peened samples show compressive stress. Compressive stresses in the range of 111MPa to 118MPa are induced by water jet peening, of which the samples peened with 50mm Stand-Off Distance (SOD) has more compressive residual stress. Samples peened with SOD of 50mm shows good corrosion resistance, micro hardness and good surface finish when compared to samples peened with SOD of 75mm. It has been observed that only SOD plays an important role in enhancing the properties after peening. The microstructure of the peened region in the weldment consists of fine grains due to impact of high pressure water jet.*
KEYWORDS*: 316L SS, TIG welding, WJP, residual stress, SCC rate, weight loss method*

1 INTRODUCTION

Austenitic SS Type 300 series (18% Cr & 8% Ni with Mo, Ti, Ni, Cu, N) is known for its excellent corrosion resistance, better creep rupture strength at high temperature and impact resistance at low temperature. Main applications of 300 series are industrial plants, chemical processing, food production, marine hardware, furnaces, heat exchangers etc. Type 316 the most common grade of stainless steel 16%Cr, 10%Ni, and 2% Mo. The molybdenum is added to help resist corrosion to chloride environment (sea water).Residual stress in welding are induced by temperature gradient during welding. Weld zones subjected to high heat input are more prone to residual tensile stress. It can be minimized by inducing surface compressive stress by various mechanical surface strengthening treatments such as shot peening, laser shock peening, surface rolling and water jet peening.

Water Jet peening is a cold working process that can impart compressive residual stress in the surface and subsurface layers for enhancing the fatigue life of the components used in various applications. In this process, high velocity water droplets continuously impinge over the surface causing localised plastic deformation of materials and stretching of the layers of the surface. It is a force controlled treatment that induces compressive residual stresses in the surface and subsurface layer without modifying the surface topography.

Rajesh et al. [1] studied three zones of water jet peening process under parameters to be considered in WJP. Using FEA the conditions of water jet peening are induced and corresponding residual stress variation in Aluminium is analyzed. Ramesh Balan et al. [2] explained that peening duration, pressure and SOD are the most important parameters influencing WJP. The flat nozzles of WJP promotes uniform pressure distribution resulting in better surface finish. In cylindrical and conical nozzles pressure distribution varies due to scattering. It has been observed that increasing the peening duration can increase the compressive residual stress induced at that point.

Azhari et al. [3] observed that multiple pass water jet peening process results in increasing hardness and also compressive residual stress. Optimizing the process parameter in multiple pass is the most essential step. Lowering the pressure at multiple processes results in reduction of surface roughness. WJP decreasing the surface roughness which increases the fatigue life of the component and decrease the fatigue crack initiation. Enomoto et al. [4] studied that stress corrosion cracking depends on three parameters - material sensitivity, corrosive environment and tensile stress. WJP is useful in preventing stress corrosion cracking and helps in fatigue life improvement. Creviced bend beam test of smooth and pre-cracked samples were conducted to analyze stress corrosion cracking. Exposure time was from 500 hours to 1000 hours. After 500 hours of exposure, no effect of the medium is observed. Effect of parameters like peening duration SOD and pressure were discussed. Peening duration and SOD has no effect when exceeded 2.5min/m and 30 micrometer respectively. Stresses remain compressive upto the depth of 250 micrometer from the surface. Fatigue life has been improved for both smooth and pre - cracked sample.

Masahito mochizuki et al. [5] used 304 SS and found that WJP does not generate any heat affected zone and hence it is widely preferred over other peening operation. It has been found that the stress id remain compressive for a period of 40 years. Daniewicz et al. [6] concluded that introduction of controlled compressive residual stress field is one of the potential means for increasing the fatigue resistance. The probability of leaving small areas unpeened is reduced by WJP. Conditions for WJP are simulated using FEM method and it is found that high pressure increases the surface roughness because of increased erosion rate. Optimizing SOD is the basic criteria for achieving more compressive residual stress. It has been observed that compressive residual stress increase as large as 60% of yield strength of the material.

Ramulu et al. [7] compared the strength of the material after water jet peening and abrasive water jet cutting. The degree of plastic deformation and state of material surface were found to be strongly dependent on the peening condition applied. Water jet peening introduces compressive residual stress equivalent to those introduced by shot peening and other operations. Anand Rao et al. [8] studied the effect of different filler material and current in the TIG welded joints of 310 SS. The filler material 309L having same Cr content as base metal shows better tensile strength compared to 316L & 347 fillers. Sakthivel et al. [9] studied the creep deformation and rupture behaviour of 316L(N) Austenitic stainless steel processed by activated TIG and multipass TIG welding. Activated TIG welding increased the creep rupture life of steel weld joints over MP TIG welding.

Kuang Hung Tsung et al. [10] studied the effect of oxide fluxes MnO, TiO2, SiO2, Al2O3 used in Activated TIG welding process. The use of activated TIG welding increase the joint penetration and weld depth to width ratio, thereby reducing angular distortion of weld metal. Akbari Mousavi et al. [11] studied the effect of groove in the residual stress distribution of TIG welded 304L SS. U groove has minimum residual stressed in both longitudinal and transverse direction compared to V groove. 500 V groove has minimum residual stress compared to 100, 200, 300, 400 V grooves. Srivastava et al [12] studied the effect of various parameters such as pressure, SOD, traverse speed, current, voltage and no. of passes in water jet peening of welded joints. The main variables that influence are pressure and SOD. Increasing pressure reduces the tensile stresses in the welded joints. Maintaining optimum SOD in WJP is more important.

2 MATERIALS AND METHODS

The tungsten and weld puddle are protected and cooled with an inert gas, typically argon and helium. 316L SS plates of 150x125x6 mm are welded using following TIG welding parameters as shown in the Table 1.

Current	Voltage	Traverse speed	Argon Pressure
100A	230V	68 mm/min	5 kg/cm^2

Table 1. Parameters of TIG welding

TIG welded samples are then subjected to WJP operation using high pressure water droplets, to create local plastic deformation that induces residual compressive stress on the welded surface. By varying pressure & SOD, 6 different conditions (pressure - 200MPa, 250MPa, 300MPa & SOD- 50mm, 75mm). for each pressure conditions, two SOD were used for analysis.

Hardness of TIG welded and WJP samples are then analysed using micro Vickers hardness. Residual stress measurements were carried out using XRD.. Microstructural analysis were done to visualize the microstructure of different zones of welded and peened surfaces. Surface roughness and SCC rate were determined.

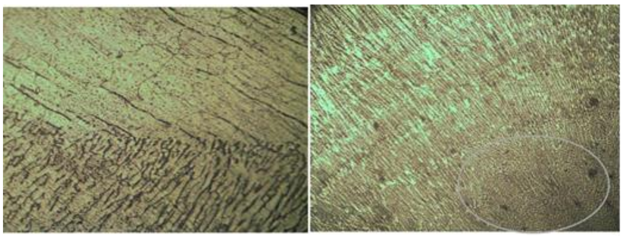
200MPa-50mm
200MPa-75mm
250MPa-50mm
250MPa-75mm
300MPa-50mm
300MPa-75mm

Fig.1 Samples welded and peened at various pressures and SOD

3 RESULTS AND DISCUSSIONS

The microstructures of as welded and peened samples observed in optical microscope are shown in the figure. The lines observed in base metal is due to multipass rolling. Discontinuous structure of columnar grains are found across the weldment along the welding direction. Fine grains are observed in the peened region. This might be due to the impact of high pressure water jet that broke the columnar grains into fine grains.

(a)Parent metal **(b) Weld region**



(c) Parent-weld interface region **(d)Peened**

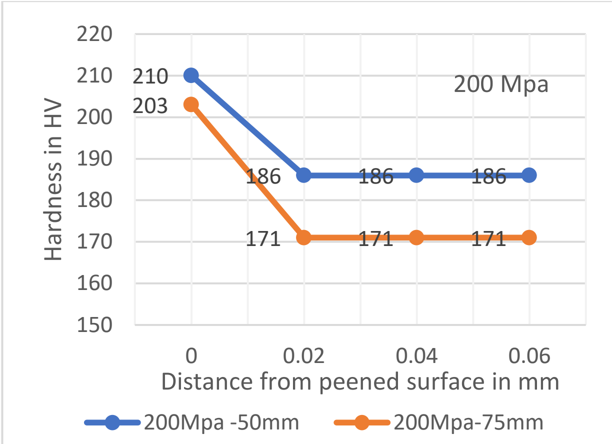
Fig.2 Optical Microscopic images of the regions

Micro Vickers hardness was used for measuring hardness variation from peened surface to distance in depth, since it is only way to measure minute variation in hardness that arises as a result of peening of TIG welded specimens.

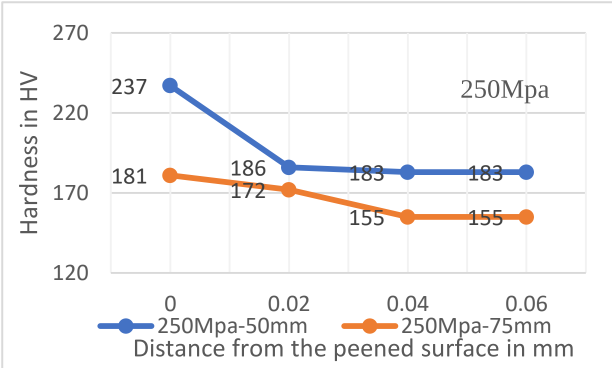
Base metal hardness – 185 HV. A load of 0.5kg and dwell time of 12s were used to measure hardness. Hardness were measured at a level of 0.02mm from the peened surface as shown in the Table 2.

Table 2. Hardness variation of WJP samples

Condition/ Distance From peened surface in mm	Hardness in HV			
	0	0.02	0.04	0.06
200MPa-50mm	210	186	186	186
200Mpa-75mm	203	171	171	171
250Mpa-50mm	237	186	183	183
250Mpa-75mm	181	172	155	155
300Mpa-50mm	225	219	210	208
300Mpa-75mm	217	208	202	186



(a)



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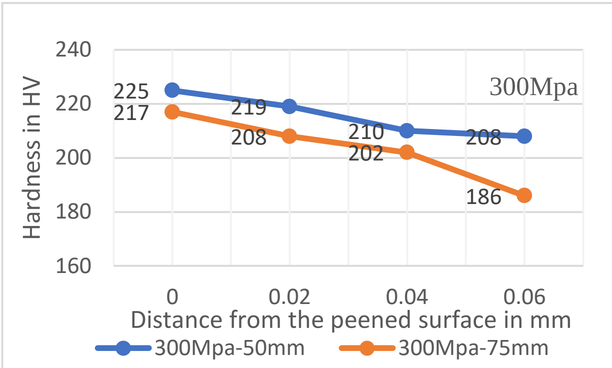

(c)

Fig. 3 Hardness Variation for Different Pressure Conditions

From the values obtained for six different condition of peening, it is observed that high hardness of 237 HV is obtained at 250Mpa-50mm but in this, depth of penetration is limited to peened region as shown in the graph. In 300Mpa-50mm & 300Mpa-75mm conditions, penetration depth extend from peened surface to 60 m with hardness of around 215HV.

It is observed that pressure and SOD plays vital role in increasing the hardness. High pressure and small SOD helps to achieve high hardness with increased penetration depth in cross section. High

SOD results in lowering the hardness value as seen in the 6 different conditions of WJP.

XRD had been used for measuring residual stress which were induced during welding & peening process.

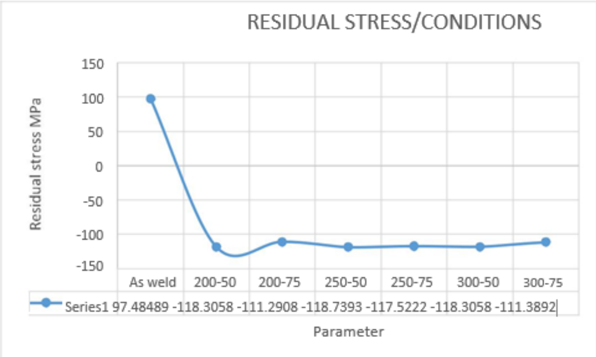

Fig. 4 Residual Stress of TIG Welded & WJP Samples

The results of XRD shows that TIG welded samples have residual tensile stress of 97.5Mpa. WJP process transforms residual tensile stress to compressive with use of high pressure water droplets. It is observed that for peened samples under 250Mpa-50mm condition, high residual compressive stress of 118.8Mpa is obtained which reflects in the high hardness of 237HV. As SOD increases, the effect of pressure in inducing compressive stresses decreased. XRD results justifies the hardness values yet high compressive stresses leads to high hardness. At 50mm, the water droplets has sufficient energy with continuous flow for creating higher stresses which is needed to strengthen the welded region while in 75mm, the path of water flow diversifies, covering larger for peening but not with much high potential for inducing compressive stresses.

Surface roughness is the combination of short wavelength deviation of the surface from the nominal surface.

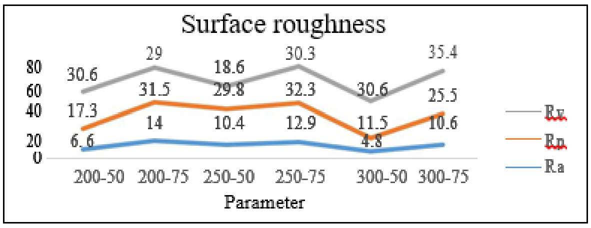

Fig.5 Surface roughness of WJP

From the surface roughness measured, it is clear that continuous flow of water is achieved only at SOD of 50mm. At 75mm SOD, the water flow loses it energy and falls in divergent manner. As there is no continuous flow of water at this distance, surface roughness values are high compared to other conditions. When the effect of pressure is considered in surface roughness in this process, it has not much significant effect in varying surface roughness. Thus it is understood that continuous flow of water alone determines surface roughness. Moving towards the nozzle of the water jet, finer surface texture might be achieved and moving still closer beyond a particular distance will result in material removal instead of peening which is not preferred.

Corrosion rate is measured using weight loss method. The samples are immersed in the corrosive environment of concentrated hydrochloric acid (35%) for a time period of 48 hours. Concentrated HCl was chosen as corrosion environment (chlorine environment – the most influencing cause for SCC) as it is most effective corrosive medium. It undergoes following chemical reaction, forming a corrosion product – $FeCl_2$

$$2Fe + 4Hcl \quad 2FeCl_2 + 2H_2$$

Weight loss in milligrams is measured for every 24 hours and corrosion rate in miles per year are calculated and tabulated and shown in Table 3.

Parameters	weight in gms (after 24 hours)	weight in gms (after 48 hours)	corrosion rate	Percentage increase
as weld	4.833	4.664	0.00169	-
200MPa-50mm	4.88	4.754	0.00139	17.575
200MPa-75mm	4.624	4.528	0.00149	12.018
250MPa-50mm	4.69	4.632	0.00065	61.598
250MPa-75mm	4.701	4.635	0.0013	22.759
300MPa-50mm	4.781	4.745	0.00043	74.477
300MPa-75mm	4.873	4.87	0.00085	49.716

It is observed that the corrosion rate of the sample peened under the condition 300MPa-50mm, 75mm shows better stress corrosion resistance when compared to other peened parameter and the as welded sample. The samples peened with 250MPa-50mm also has high resistance towards stress corrosion which indicates that inducing high compressive stresses will results in increased resistance towards stress corrosion. Considering the results of surface roughness in SCC, samples peened at minimum SOD (50mm) has lower surface roughness which leads to increased resistance of stress corrosion. Rougher surface will act as a site for corrosion. Thereby optimising the parameter that will create low surface roughness with high compressive stress helps to achieve much better resistance toward SCC.

The samples peened with SOD of 50mm shows reduced stress corrosion rate when compared to 75mm SOD samples. This effect is observed due to the presence of high compressive residual stresses induced by high pressure water droplets with SOD of 50mm. Samples peened with high water pressure and smaller SOD shows increased resistance towards stress corrosion.

4 CONCLUSION

An exploratory research on water jet peening of TIG welded 316L SS plates was conducted using 6 different conditions by varying pressure (200,250 & 300MPa) and SOD (50 & 75mm). It was observed that high pressure water jet creates local plastic deformation, thereby inducing residual compressive stress on the weld surface. WJP with 50mm SOD shows better properties compared to 75mm.

- Columnar grains of TIG welded samples becomes finer grains after water jet peening on the surface level
- High hardness of 237 HV was obtained on 250MPa-50mm condition but effect of peening is limited to surface level whereas 300MPa (50 & 75mm) condition results in high depth of penetration of hardness from surface to subsurface level.
- High residual compressive stress of 118.8MPa is induced on the surface when peened under 250MPa50mm condition.
- Surface roughness depends mainly on SOD & not much on pressure was recorded. WJP with 50mm SOD shows lower roughness which was the result of continuous flow of water.
- Stress corrosion resistance increases for 50mm compared to 75mm and high resistance towards stress corrosion was observed on 300MPa (50 & 75mm) and also on 250MPa-50mm condition as a result of high residual compressive stress induced by high pressure water jet.In this part will be emphasize the contributions of the paper and the future applications in the research field.

5 ACKNOWLEDGEMENTS

Any acknowledgements would be written in this section.

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