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EVALUATION OF ANISOTROPY AND STRAIN HARDENING EXPONENT OF SS304L TAILOR WELDED BLANKS

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ABSTRACT

Computation of planar/normal anisotropy and strain hardening exponent is a key process to evaluate the formability of sheet metals. In this work, a comparative study has been performed between as received and autogenously TIG welded sheets of SS 304L. Uniaxial tensile tests were carried out on along three directions, along (0°), across (90°) and diagonal (45°) to the rolling direction and the corresponding anisotropic values were calculated. Metallography by optical microscope was carried out in order to correlate the tensile test results. Tensile test results show that yield strength (σ_y) of welded sample was found to be higher than as received samples, whereas the ultimate strength (σ_u) values have decreased. The higher dislocation density and the relative higher hardness in the weld metal zone is attributed to this mechanical behavior. The normal anisotropy (r_m) and strain hardening exponent (n) of the TIG welded samples are found to be greater than values of as received samples.

Key words: *Anisotropy, Strain hardening exponent, SS304L, TIG Welding.*

1. Introduction

Sheet metal forming is one of the most widely used technologies in manufacturing industry. The ever increasing demands from automotive sector are the main driving force behind the sheet metal forming innovations. Earlier In sheet metal industry there were only two methods to obtain the final panel, first method was disintegration method, in which each part were formed separately and then welded together to get final shape of panel, but this method associates with large number of forming operations which is not an economical choice. Second method was integration method, in which final panel was obtained from a single sheet which cuts the large number of operations required, but this method forces to use single material with uniform thickness and hence kills the flexibility.

This necessitates the idea of Tailor Welded Blanks (TWBs). Tailor welded blanks can be defined as Joining of materials may be of different compositions, thickness, coatings, by suitable joining method before forming operations. Though TWBs provides better design flexibility and economical way of production this TWBs are more complex in the metallurgical sense. In sheet metal forming quality of final output is driven by no of terms like plastic strain ratio (r), normal anisotropy (r_m), planar anisotropy (Δr), and strain hardening exponent (n). The plastic strain ratio (r) is a parameter that indicates the ability of a sheet metal to resist thinning or thickening when subjected to either tensile or compressive forces in the plane of the sheet. This resistance to thinning or thickening contributes to the forming of shapes, such as cylindrical flat bottom cups, by the deep-drawing process. The r value therefore, is considered a measure of sheet metal drawability. The normal anisotropy is an average value of plastic strain ratio in three directions i.e. along (0°), across (90°) and diagonal (45°) to rolling direction and it can be calculated as,

$$r_m = \frac{r_o + 2r_{45} + r_{90}}{4} \qquad (1)$$

Whereas planar anisotropy is nothing but the defect also called as an earring tendency, earring mean fold like structure along cup length, this planar anisotropy reduces the yield of the material and calculated as, [1]

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$$\Delta r = \frac{r_o - 2r_{45} + r_{90}}{2} \tag{2}$$

Strain hardening exponent determines how metal behaves when it is being formed; this 'n' shows the relation between the true stress and true strain during plastic deformation. It is the measure of increase in hardness and strength caused by plastic deformation [2]. Syed et al developed forming limit diagram for SS316, it is observed that calculation of anisotropic characteristics and strain hardening exponent is important to develop Forming Limit Diagram (FLD) theoretically [3]. Narayansamy et al worked with three different sheets Viz. HSLA, C-Mn and micro alloyed and developed FLD, researchers found that higher the strain hardening exponent (n) and higher the Plastic strain ratio (r) better the formability of material. [4]. Ravi kumar et al worked on tailor welded interstitial free (IF) steels and they found that there is slight improvement in yield strength and strength coefficient but negligible change in strain hardening exponent (n) [5]. Sushanta Kumar Panda worked on IF steels and IFHS steel sheets, from the limiting height dome test it is observed that the height of dome is higher in IF steels than IFHS due to the higher value of n obtained for IF steels [6]. Xiang-dong et al worked on ST12 cold rolled steel sheets of thickness 0.8mm and 1.2mm to develop FLD researchers calculated the anisotropy and found the higher anisotropy in higher thickness samples also anisotropy is found to be maximum in diagonal direction [7]. Leandro de arruda santos et al studied the strain hardening behavior of three steels NGOE steel, AISI 304 and Dual phase steel, in this study after uniaxial tensile test XRD and optical microstructure evaluation were carried out; results shows that AISI 304 steel shows the highest Strain exponent value (n= 0.46) among all due to its tendency to produce martensite during plastic deformation also XRD analysis shows that n value is influenced by strain induced martensite [8]. In this current work efforts have been invested to understand the importance of plastic strain ratio, anisotropic characteristics and strain hardening exponent in the need of high strength as well as good formability of SS304L TWBs.

2. Materials and Methods

The material chosen for this research is austenitic stainless steel type 304L, as received material was in the form for cold rolled sheets of 1.55mm thickness. The chemical composition of material is listed in Table.1 below. Three tensile test specimens were drawn out from each direction (0°, 45° and 90°).

Table 1. Chemical composition of SS304L

El	C	Cr	Ni	Mn	Si	Mo	V	Cu	Fe
%Wt	0.03	17.73	8.48	1.6	0.6	0.07	0.08	0.15	Ba

Two sheets of size 50x200mm were used to fabricate welded sample, and tensile test specimens were drawn out from it by using wire EDM. The welded samples were fabricated by automatic autogenous TIG welding facility of Ador fontech Ltd. model (TZ3BS4BY4), since the thickness of sheets was small square butt joint design was selected without any groove preparation. The process parameters are mentioned in Table.2

Table 2. Welding Parameters.

Sl. No	Current (A)	Voltage (v)	Speed (mm/min)	Argon Purging (SLPM)
1	70	10.5	170	12

The mechanical properties and anisotropic behavior were evaluated by uniaxial tensile test carried out at room temperature using Universal Testing machine (Hung-Ta, HT-2402) at constant strain rate of $3x10^{-4}s^{-1}$. Specimens were prepared as per ASTM E8 [9] and test procedure was followed according to ASTM E517. [10]. Microscopic analysis was performed under Laser Confocal microscope (Olympus 4100) on as received and welded samples.

3. Results and discussion

3.1 Microstructure Analysis

Fig.1 shows the typical micrograph of type 304L stainless steel, it illustrates microstructure at base metal, which shows equiaxed grain structure with some twin boundaries. This microstructure is combination of austenitic phase and Ferritic phase.

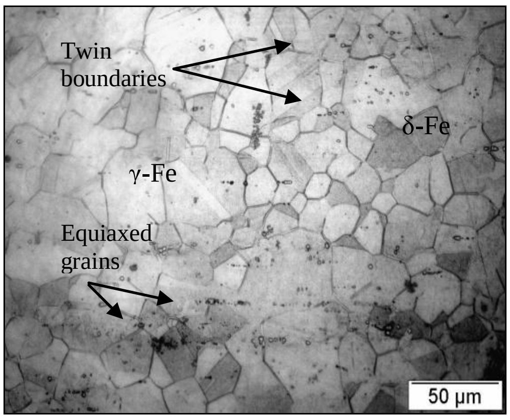


Fig.1 Typical microstructure of SS304L

Microstructure of austenitic stainless steel is supposed to be fully austenitic but in Fig. 1 and Fig. 2 we can find the traces of δ ferrite, The reason is addition of over 2.5% of ferrite promoters by steel makers in austenitic stainless steels to improve the hot workability [11].

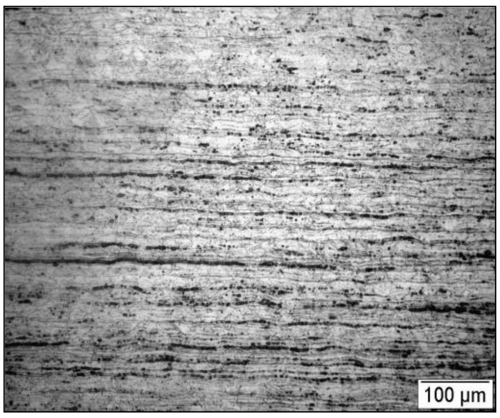
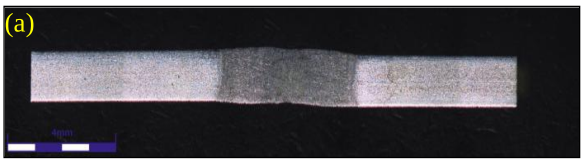


Fig.2 Cross-sectional microstructure of SS304L along rolling direction.

This directional changes in the microstructure acts as an anisotropy in materials. Fig. 3 (a) shows the overview of the TIG welded sheet.



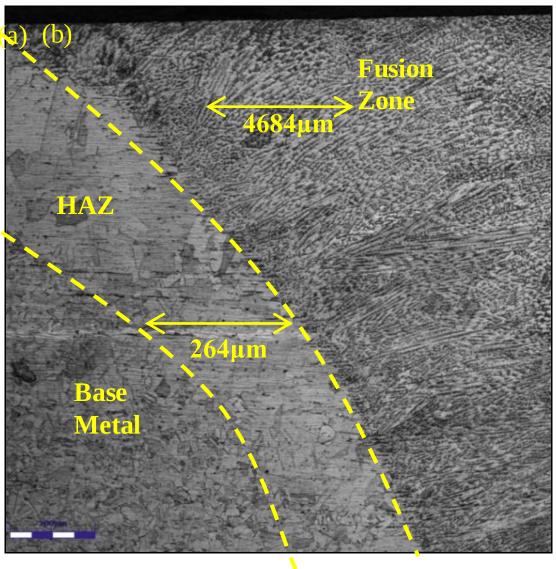


Fig.3 (a) Overview of weld cross section. (b)Microstructure at weld joint interface

Fig. 3 (b) shows the interface zone where we can observe the fine dendrite structure with presence of δ-ferrites in fusion zone, this fine dendrite structure indicates the good weld strength. For every welding HAZ is expected to be narrow as it shows the coarse grains which are not desirable in point of view of strength. We can observe that as compare to fusion zone HAZ is very narrow; it accounts for 250µm only whereas fusion zone accounts for 4684µm.

3.2 Tensile test

From the of tensile tests, stress strain plots of 0°, 45° and 90° were presented in Fig. 4, Fig. 5, and Fig. 6 respectively. The plots were intentionally overlapped to compare as received and welded specimens. At an outset, the tensile tests revealed that the percentage of elongation encountered in as received and welded 304L specimens were 108.27 and 68.29 respectively. The obvious reason behind reduction in percentage of elongation is the metallurgical changes induced in welded samples, rapid cooling of weld portion is accountable for the formation of fine grains at fusion zone, and the same is observed in Fig. 3 (b). It reduces the ductility of material. However, on the other hand fine dendrites are responsible for the higher hardness values [12].

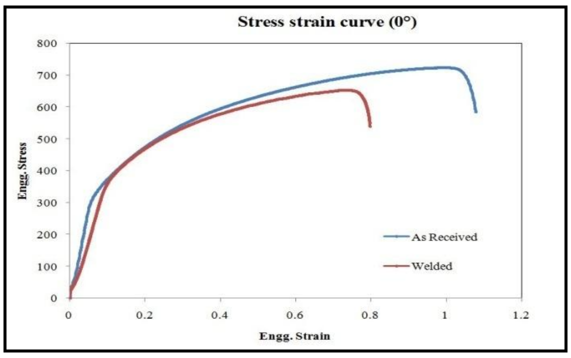


Fig.4 Stress-strain curve of as received and welded samples along rolling direction

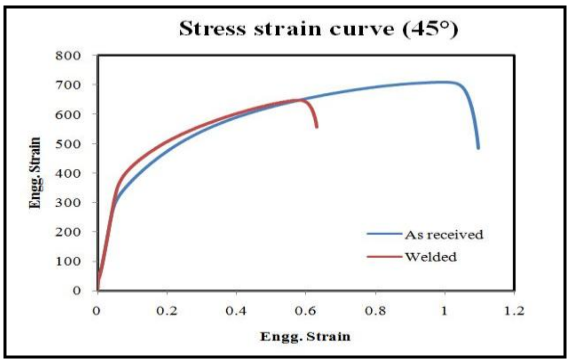


Fig.5 Stress-strain curve of as received and welded samples along diagonal direction

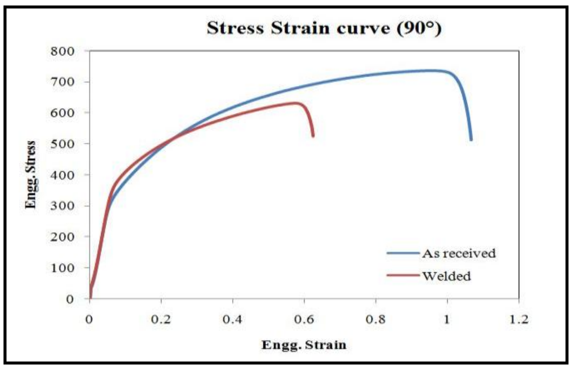


Fig. 6 Stress-strain curve of as received and welded samples along diagonal direction

The yield strength of as received material is found to be 284MPa, whereas it is 345MPa in welded specimens; the marginal rise in the strength is due to the higher hardness and high dislocation density in the weld metal zone. Further, 304 L has very low amount of carbon content and the chances of forming secondary phases is limited. In the other hand, the autogenous TIG welding employed in this TWB joining excludes the chances of enrichment of alloying elements, thereby the fusion zone, which is analogous to the cast microstructure will have increased yield strength as expected. The region between the yield point stress and the ultimate stress portrays the strain hardening zone of the material. The higher dislocation density and the higher hardness values in the weld material zone are responsible for the increased yield point stress values compared to the as received sheet samples. As the weld metal zone possesses higher dislocation density, the zone cannot accommodate further more strain. It resulted in the decreasing of ultimate tensile strength compared to the as received sheets. This phenomenon attributes the premature failure in the tailor welded sheets during tensile testing.

Table 3. Mechanical properties of SS304L

Sl. No	**Particulars**	**YTS (MPa)**	**UTS (MPa)**	**%Elongation**	**Hard ness (HV)**
1	As Received	284	721	108.27	160
2	TIG Welded	345	640	68.29	198

The factors that determines the formability like Plastic strain Ratio and Strain hardening exponent (n) were calculated as explained elsewhere [10], with help of Holloman Equation and

$$\sigma = K\varepsilon^{n} \qquad (3)$$

From tensile test data strength coefficient (K) were determined as explained elsewhere [13,14].

Table 4. Strain hardening exponent

Sl. No	Particular	Orientation			Avg 'n'
		0°	45°	90°	
1	As Received	0.401	0.362	0.395	0.380
2	Welded	0.518	0.423	0.430	0.448

Average = $(n_0+2n_{45}+n_{90})/4$

From the above table it is observed that n value of welded samples is higher than as received samples. 'n' value defines how material will behave during plastic deformation, for any material n value lies between 0 and 1; where 0 indicates perfectly plastic and 1 being perfectly elastic solid, this means higher the n value better is the formability. The normal anisotropy

(r_m) and the planer anisotropy (Δr) were calculated from the r values determined along three directions namely along (0°), diagonal (45°) and across (90°) to the rolling direction using the following expressions

$$r = \frac{\varepsilon_w}{\varepsilon_t} \qquad (4)$$

Where ε_w is true strain in width and ε_t is true strain in thickness

$$r_m = \frac{r_o + 2r_{45} + r_{90}}{4} \qquad (4)$$

$$\Delta r = \frac{r_o - 2r_{45} + r_{90}}{2} \qquad (4)$$

Summarized values are listed in Table 5.

Table 5. Anisotropic values

Sl. No	Particular	Average n	Average K (MPa)	Average r_m	Average Δr
1	As received	0.380	1752.62	0.9071	-0.0547
2	TIG Welded	0.448	1658.42	1.069	-0.077

For isotropic materials the normal anisotropy clue is one. It is always desirable to have high normal anisotropy value, as it implies the high resistance to thinning and a good strength in transverse direction. Generally, for stainless steels r_m value lies between 0.9 and 1.2, since the material is not isotropic there will be some amount of planar anisotropy can be observed. One can expect zero planar anisotropy, in order to avoid earring tendency which eventually reduces the yield of material. [15] In this study, planar anisotropy values are found to be closer to zero but negative; physical significance of negative value is that material has become more susceptible to thinning and rupture when loaded in diagonal to rolling direction [16]. Mathematically it can be expressed as,

$$2 \times r_{45} > (r_0 + r_{90}) \qquad (5)$$

4. Conclusion

Following conclusions can be drawn from results and discussion chapter

- Yield strength of welded SS304L specimen found to be higher than as received specimen, due to the presence of fine grains in fusion zone of the weld metal.
- Average strain hardening exponent (n = 0.44) is found to be higher in TWB specimens, which indicates that welded specimen possess relatively higher strength with a loss of ductility to certain extent.
- Normal anisotropy value observed to be higher in welded samples, which imply good resistance to thinning during deformation.
- Planar anisotropy values for both welded and as received material are found to be negative, which indicates that material has susceptibility to thinning if it is loaded in 45° to rolling direction.

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