Formability of Laser Welding Plates of Dissimilar Materials

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Abstract. Hydraulic deformation is a procedure utilized for forming sheet by applying the pressure driven pressurized fluid on the sheet. This procedure is described by its capacity to give homogenous strain distribution along the blank with high mechanical properties. The analysis of the sample deformation process has performed by using circular welded plate by laser technique of dissimilar steel plate (SS304-St1008) with thickness 1mm using profile radius for lower die 2 mm under the effect of blank holder force 10 kN. The metal thickness checked and the SEM test investigated for the formability product of laser welded plate. Discoveries show that by and large better mechanical characteristics, for example, formability, tensile and yield strength of welded joints can be achieved by using laser welding and the blank deformation becomes uniform with the hydraulic force. It is useful to avoid thinning of the blank with suitable friction coefficient between the die and the blank. Based on the experimental results of dissimilar metal, it found, that the joint weld strength parts, was lesser than the base strength, so the fracture is occur on the base metal. The SEM investigation indicated that the joining process between the SS304 and St1008 was occurred by heating due to laser on the other hand the depth of the interface between the joint materials had the range of 3-5 µm . The EDS examination indicated that the interface zone of the jointed contained Cr, Ni, C and Fe, the left side is SS304 passing through the region zone and ending with St1008, the ratio of Fe increased and the other elements decreased.

Keywords: Deep drawing process, SS304 metal, St1008 metal, Laser welding, Butt joint, Formability, hydropunch, hydroforming process.

1. Introduction

This paper includes the welding work; Laser welding of dissimilar materials and its mechanical properties, in addition to formability of the welded blanks via hydro deep drawing process, also the macrostructure, x-ray test are observed. Satya Suresh V. V. N. et al., (2016) [1], studied the heat forming of a welded of tailor blank (TWB) which in two or more material blanks are welded together and exposed to localized heating before forming to get a square cup shape, the weld line shift of TWB’s of two different materials namely IFHS and DP 590 has studied. Arman Khan et al., (2014) [2], Studied a Tailor-Welded Blank (TWB) that gotten by welding together sheets of same or distinctive metals of various thicknesses to deliver the single blank to exposing it to a forming process, Aluminum (AA6016-T4) blank sheet was joined with two high strength steels (HSLA-340 and DP600) using three ratios of thickness (Steel/Al) of 1.0, 1.25 and 1.5 to form 6 various joins. Bhanodaya Kiran Babu NADIKUDI et al., (2015) [3], studied the “tailor welded blanks (TWBs) made by friction stir welding (FSW) with five different tool pin profiles”. N.F.M. Selamat et al., (2016) [4] , in this study, the friction stir welding (FSW) known as the solid state joining process has extensively used for joining similar and dissimilar 5 mm aluminum alloy plates. The butt-joint type of similar joints (AA5083-AA5083) and dissimilar joints (AA5083-
AA6061) were carried out under the same welding parameters; 1000 rpm (rotational speed) and 100 mm/min (transverse speed). Mohammed Hasan Shahriyar (2012) [5] investigated the friction stir welding (FSW) can defeat three noteworthy disadvantages of Laser welding procedure to create TWB for the vehicle business. It has recognized that a few kinds of Aluminum to Aluminum combination, few joints of high strength steels (HSS) to HSS joints and steel to aluminum joints are troublesome to deliver by laser welding.

The objective of this research work is to investigate and develop a better understanding of the effect of laser welding on the formability (hydropunch deep drawing process) aspects of the dissimilar material (steel 1008 – steel 304).

2. Non-destructive Tests

The specimen preparation and joint design and Laser Welding type pulsed Nd:YAG laser system class four 1.064μm model PB 80 made by Han's Laser Technology Co. Ltd. mention in details in Ref.[6].

2.1. Visual inspection results

Visual tests are the first of tests that are used before, during and after the welding process. In this test, many defects can be discovered with the eye then evaluated directly if they were acceptable or not. Visual test of weldment has applied in three stages:

1. Prior welding process.
2. During the welding process.
3. After the welding process.

2.1.1. Prior Welding Process

This stage of visual inspection includes more functions such as checking the weld joint preparation, edges finishing, and other features that might affect the quality of the weld. Generally, the following matters have checked.

- Machine parameters and the adjusting process.
- Welding procedures.
- Joint preparation, dimensions, and pre-cleaning.
- Good finish of two pieces (plate) edges that will be welded and fixed together (butt joint) without a gap between them; this gap if it exists affects weld quality and causes defects in welding line.
- Fixture setting, alignment, and the two pieces clamping to prevent any movement during welding process.

2.1.2. During Welding Process

The second stage of visual inspection begins with the start of the welding process and perform the checking:

- Surface of weld line if defects exist which are due to tool or shoulder heel
- Excess flash of metal due to excessive plunging tool depth.
- Smoothness of weld face.

2.1.3. After Welding

Matters that have inspected through this stage of visual inspection include weld line dimensions (plunging and width), angular distortion of the joint, misalignment of the weld, back surface cracks, and lack of penetration (L0P). The samples have excluded for the above reasons as illustrated in Figure 1.
2.2. X-Ray Inspection
The samples that have already passed from VT test were tested by X-Ray inspection to ensure that they are free of cracks and they succeeded in that with small or no defects present. Figure 2 illustrated the weld line which was homogeneous and clear without cracks, tunnels except referred to. From the welded region (B) it has seen that there is a surface defect due to incomplete heat flow.

2.3. Microstructure Examination Results
The microstructure examination results for similar and dissimilar alloy specimens that were welded by the laser are different from that of the base metal microstructure or cast structure of fusion weld, Figure 3 shows a sample of this joint.
The joint consists of four zones:

❖ Nugget zone (NZ) or weld nugget at the weld center which is fully re-crystallized region.
❖ Thermo-mechanically affected zone (TMAZ) which is influenced by warmth and deformation, but is not re-crystallized at both side nugget zone.
❖ Heat affected zone (HAZ) which is influenced only by heat without deformation of plastic between (TMAZ) and (BM).
❖ Base metal (BM).

Figure 4 illustrated the cross section of optical photos of the welded parts by laser for the dissimilar specimen. A uniform weld pool can be noticed for the welding.

Figure 4. The cross section optical photo of laser welded SS304 to St1008 at constant beam energy

the welding investigation, has a little plunger at the top surface of the SS304 sheet since the vanishing procedure is happened, the outcomes in scattering of the measure of laser beam intensity, which makes the uniform pool of weld. Additionally higher peak intensity and high coupling have get by the increasing in porosity and decreasing in the quality of welding. The base metal zone (BM) is unaffected material or parent metal that is remote from the weld and that has not been distorted or influenced by the heat in terms of the microstructure or mechanical properties.

3. Destructive Tests

Tensile testing was performed to determine the mechanical properties of the welded samples and comparing them with the base metal. The main purpose of this test is to find the behavior of the samples in the stress-strain curve through which the efficiency of the welds and ultimate tensile stress have calculated.

The tensile test results showed that all welded samples had failed in the welding region for similar material and in the base metal of St1008 in dissimilar material. This due to the change in the mechanical and metallurgical properties of both materials during the welding process. Figure 5 shows tensile specimens after testing.
Figure 5. Tensile specimens after testing.

Figure (6) shows the stress-strain curves for unwelded and welded steel metal.

Figure 6. Stress-strain curve for unwelded and welded steel metal

4. Hydro Deep drawing process
The hydro deep drawing process has achieved by using die oil as lubricant, to form a hemispherical cup from SS304 with St1008 (dissimilar material) alloys welded blanks.

The hydro deep drawing process was performed for several samples from the highest ultimate tensile strength to the least. The drawing speed using in the practical work is 1mm/min. one case for dissimilar materials (SS304-St1008)

5. Blank of Dissimilar Material (SS304-St1008)

5.1 Wall Thickness Distribution:
In the estimation of the work-piece element, first, wire cutting machine was utilized to cut a fourth of the part along the middle line, at that point the thickness values of the forming work-piece were estimated in the ways from center to the outside edge with aid of profile device.
The relationship between thickness wall distributions is found. It has observed that the thickness varies under the hydraulic punch base. Where the deformation occur in this area due to no friction which prevents any deformation of the metal under the hydraulic punch. At the next zone, thinning will occur due to an increase stretching exerted by the high tensile stress in this area and then increases on the cup wall thickness until it reaches a maximum value. The hoop stress (circumference) tends to thicken the blank at the end of the cup wall.

Figure 7 illustrates the wall thickness distribution in the StSt304 side cup while Figure 8 illustrates the wall thickness distribution in the St1008 cup.

Figure 7. wall thickness distribution in the StSt304 side cup

Figure 8. wall thickness distribution in the StSt1008 side cup

At the point the hydro punch get in contact with blank, the blank thickness varied. When the stroke was around 6 mm in the center stage of the forming procedure, in light of the fact that the illustration had not finished yet, there were still a flange state at the blank edge and a vary at the straight thickness of wall of the blank because of the proceeded with activity of hydro punch press. Along these lines, the even stretching decreased further the blank thickness. Furthermore, the blank in the part of the fluid, especially towards the long axis of the punch, had significant changes in thickness. Hence, the region suffered the largest circumferential tensile stress; and with the increase of the punch stroke, the thickness in the direction of the long axis became thin. “In addition, the thickness of the blank in the direction of St1008 side axis of the punch got thinner with the increase of hydro punch stroke. However, the circumferential tensile stress was less due to a larger radius of curvature in the geometric shape in the direction of the St1008 side. Therefore, the changes of the thickness in the St1008 side axis compared to the St304 side axis in the overall level are not significant”.
5.2. Strain Distribution:
Figure (9a) shows the hemispherical cup of dissimilar material and Figure(9b) explains the load-displacement curves for hydropunch deep drawing process for SS304, At1008 and the welded plate from the St304 vs St1008. Figure(10a) illustrates the radial strain distribution from StSt304 side and Figure(10b) illustrated the radial strain distribution from StSt1008 side.

![Figure 9a. Hemispherical cup of dissimilar material](image)

![Figure 9b. the punch-displacement curves](image)

![Figure 10. Radial strain distribution](image)
6. EDS result

EDS test using higher magnification for inspection and the result in weld St304 to St1008 at Nugget Zone (NZ) have some element in this alloy such as (C, Br, Cr, Ni and Fe-rem.) as shown in figures 11-(12), that’s Figures(6-14) illustrate the distribution of the elements. Figure 13 represents the ratio of Cr, Ni, C and Fe, the left side is SS304 passing through the region zone and ending with St1008, the ratio of Fe increased and the other elements decreased.

Line scan analysis of energy dispersive spectroscopy (EDS) analysis was carried out to determine the elements distribution across the joint of the SS304 and St1008. Figure 13 shows the EDS spectra line scan across the base material and the bonding zone which indicate the element identification of SS304 and St1008 joint. The surface energy of SS304 and St1008 differs considerably. This affects the adhesive bonding at the interfaces of these two materials. Also, these metals have completely different structures. The interface layer is composed mainly of C, Br, Cr, Ni and Fe as shown by EDS analysis, that in addition to mechanical interlocking and Vander Waals force there is a chemical reaction between metal. Actual chemical bonding occurred at the interface caused by thermos-mechanical effects of Laser welding process.

![Figure 11. EDS inspection for dissimilar Laser weld st304 to SS1008](image-url)
Figure 12. Mapping of elements in Laser weld joint.

Figure 13. EDS map line scan of SS304 to St1008 joint.
7. SEM result

Figure 14 illustrates the device for SEM, which examination has used to identify the behavior of joining mechanism between the dissimilar materials and determine the thickness of joining layer between those materials. Figure 15 illustrates the SEM images of joints SS304 and St1008 with 10, 20, 50, 200 µm magnification.

The line of the interface was clearly observed for each type of joint. Mechanism is the jointing mechanism between the SS304 and St1008 without cavities. The average thickness of the interlock line between the SS304 and St1008 was 5 µm. Hence, the higher generated temperature resulted in a tighten built in along the interface line without gaps. Figure 15b demonstrates the welding region the left side is SS304 and the right side is St1008.(200µm). Figure(15g) shows the welding region, the left side is SS304 which is not clear due to the etching solution is suitable for low carbon steel and the right side is St1008.(10 µm). Figure 15e explains the welding region.(20 µm). Figure(15d) illustrates the welding region with asperities which is expanded due to drawing process.(50 µm).

Figure 14. ESM device
Figure 15. SEM images of SS304 – St1008 interface at 10, 20, 50, 200 µm magnification
8. Conclusions
The following points are concluded:

1. Welding of Laser is a success process for combining dis-similar materials, where the welded joints strength was lesser than the base metal strength.
2. A technique for the control of hydro punch process has presented. This technique is based on the use of fluid as a punch. This technique is better than the classic deep drawing.
3. Extensive experimental of sheet hydroforming procedure achieved in this paper. The variation of thickness along the x-axis is investigated experimentally along the distance from the middle of sheet metal.
4. Findings indicate that in many cases better mechanical qualities such as formability, tensile and yield strength of welded joints can be achieved by using laser welding.
5. The blank deformation becomes uniform with the hydraulic force. It is useful to avoid thinning of the blank with suitable friction coefficient between the die and the blank.
6. Based on the experimental results of dissimilar metal, it has found, that the joint strength of the welded parts, was larger than the strength of the base, so the fracture exists on the base metal.
7. The SEM examination of joint cross indicated that the joining process between SS304 and St1008 has achieved by laser welding.
8. The EDS examination indicated that the interaction line between the two materials contained the elements Cr, Ni, C and Fe.

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