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A Review of Research Progress on Dissimilar Laser Weld-Brazing of Automotive Applications

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Abstract. In recent years, a rapidly growing demand for laser brazing in the transportation industry for automotive parts joining to improve the productivity, quality of the joints and cost efficiency reasons. Due to this, laser brazing technology is extensively used in the major manufacturing companies such as Volkswagen group, General Motors Europe, BMW and Ford manufacturing groups as their openingbulk production solicitation on various parts of vehicles. Laser brazing is different from the welding processes and it will block upanopeningamongst two substrates by mixture of a filler wire on condition that by a concentrated laser beam or any other heat source. Among the all joining processes, laser brazing technique is an alternative and in effect method for welding of dissimilar metals which have large difference in their melting points. It is important to understand therelationsof these phenomena of the fillers of brazing with the substrate surfaces to obtain a high quality joints. The aim of this study is to address the contemporaryenquiriesand its progress on laser-brazing, its importance to the industrial applications and to bring more awareness to the manufacturers about the research results of this technique from various research groups to enhance the research progress and developing new things from this review report.

1. Introduction

Laser brazing has become decisively recognized as a joining process for sheet metal joining in the automotive industry. At the end of the nineties laser brazing was used in the manufacturing sector for joining of various parts of vehicles. Initially it has introduced in the first industrial applications in 1998, the continuous production with the development of such a process with the high quality systems led to the increases in its importance [1]. Laser brazing is nowadays widely used and it became a standard process in automotive industries around the world. The outcome of the quality of the laser brazing joints in comparison to other joining processes has better performance and many advantages. Laser brazing joints are ductile and leak proof at low processing temperatures and ability to produce robust joints [2]. One of the major advantages of especially for the sheet metal joining is to keep minimum thermal impairment to the substrate metal and low thermal distortion for the welding parts, which is major drawback for conventional fusion welding joints. In addition, laser brazed joints are exhibits high quality surfaces and the process is fully automation. Due to these unique qualities of the process, it is widely used in car body manufacturing especially for the components in the visible areas such as roof joints and tail gates [3].To improve the corrosion properties of the automotive parts are electro galvanized coating are generally apply to the base metals. The most commonly used filler material for automotive steels is silicon bronze which is abbreviated as $CuSi_3$. Even though these progressions in the process, there are various types weld seam imperfections still appear in the final joints. The imperfections which are related to metallurgical reactions like an unintentional melting of the base meals or the formation of brittle intermetallic compounds [4]. These intermetallic compounds formation can deteriorate the joint quality systems. The results are similar to the joining of dissimilar metals using conventional fusion welding techniques. The most commonly used dissimilar materials combinations in automobiles are aluminium and stainless steel are joined by using various welding techniques to achieve the high performance of the joints. Conversely, there is a serious problems encountered across these joint interfaces when arc welding practices used for instance gas metal arc welding [5], laser welding [6], TIG arc welding–brazing [7]. On the contrary, solid state joining has been contemplated as a trustworthy welding method for incompatible metals' (such as steel to aluminum, titanium to steel, steel to magnesium, aluminum to titanium, copper to aluminum, etc.) that are very difficult to conventionally fusion wieldable. These combinations are successfully joined by using solid state welding methods for example friction stir welding [8-12], friction welding [12-21], explosive welding [22], diffusion bonding [23,24]. However, there are few types of joint combinations still existence with the formation of intermetallics, to suppress the further formation of avoid them interlayer mechanism was used [25-28]. But, all these joining techniques are not suitable for mass production due to a number of problems such as limited shape of the base metals, the initial preparation of the surfaces, material loss as weld flash, long weld duration of diffusion bonding and low range of process parameters selection [29].

In contrast, brazing technique is one of the most expedient and high quality joining process for dissimilar metals. As explained earlier laser welding brazing become efficient process to solve the weld joint problems and it has several advantages that complex structures, thin sheets can be brazed without any defects formation. Laser welding brazing process is an exceptional tool for governing the heat input and fusion zone extent, all are beneficial for maintain weld temperature in weld zone and reaction time of solidification in the dissimilar metals joining [30]. The existing literature shows that the results on laser joining method between aluminum and steel joints work done by the Bremer Institute fu¨r Angegwandte Strahltechnik (BIAS) used a system is called transparency laser braze welding [31].It is observed that the laser welding beam warmness the steel to its melting temperature at that temperature aluminum sheet turns melt by thermal conduction. Bergmann *et al.* [32], have been deliberate the laser welding brazing of aluminum with steel results and reported that enhancing of the mechanical properties of the joints performance are within 20% of the conventional brazed aluminum joints. It is worth to mention that the laser braze welds exhibits a local temperature energy entering input causing in a controlling of the establishment of fragile inter metallic compounds. Most importantly the solidification of the fusion zone is depends on the welding speed, the welding speed of the welding is commonly greater than that of the other welding processes. Due to this high speed welding it is most suitable process for welding of hollow section joints. In general laser brazing is contains to block up a gap amongst two substrates with the melting of a brazing filler wire delivered by using defocused laser beam as shown in figure 1 (b). To avoid the oxidation problems Ar can be used as shielding during brazing process. The complete joint filling can be control by amending the power of the laser source, welding and speed of the filler wire (see figure 1 (a)) [33].To attain noble eminence joints, it has need of an acceptable thoughtful of collaboration phenomena of the laser braze fillers using of substrate surfaces. Various studies have been performed on the optimization of process parameters, wettability, different filler materials, heat input rate, materials combination, metallurgical incompatibilities such as oxide film formation which will impair the quality of the joints. The excellence of the brazed joints also be determined by on the welding conditions during brazing operation and wetting and interfacial reactivity, and defect free joint formation. The brazing filler and laser power source together combine effect on joint formation and to avoid the cracks and nonbonding regions across the joint interface and gap between the butt joints substrates. The features of the brazing of laser joints also be subject to on the welding conditions for the duration of brazing operation and wetting, and interfacial reactivity, and the

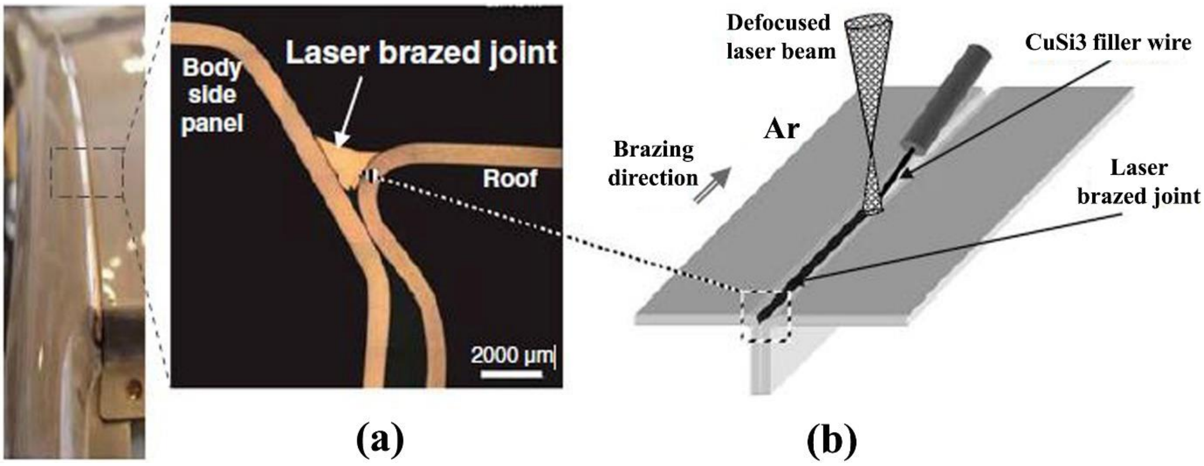

Figure 1 (a) Joints cross section view of the laser brazed welds of roof/body side panel, (b) A schematic illustrting the principle of laser brazing [33].

Defect free joint formation. Various studies have been performed on the optimization of process parameters, wettability, laser beam sources, shielding gas, different filler materials, heat input rate, materials combination, and metallurgical incompatibilities such as oxide film formation which will impair the quality of the joints. In the present study a brief review of the laser brazing process and various process conditions, and its influence on the joint performance and metallurgical characterization was conducted. The importance of the overview of laser brazing in the automotive industrial applications and its progress on recent research trend to bring the awareness for researchers for their future research direction and implementing of these techniques to enhance research progress and developing new things for various applications.

2. Research progress on laser brazing

2.1. Laser power source

The continuous growing demand for aluminium alloys in automotive industry makes challenges for joining of these alloys efficiently. Due to the formation of oxide layers and poor performance of the conventional fusion welding methods were not feasible to joint aluminium alloys. To avoid the oxide layer formation in the joint interface, Markovits [34] *et al.* used CO_2 laser beam as the heat source and studied the absorption ability of the Al surface with and without flux covered during laser brazing. They have determined the immersion capacity of the flux covered surface ultimately by computing the emission coefficient for the wave length of laser usingCO_2 and accordingly modified the composition of the flux with the purpose of expand the adsorption capacity of the flux (shown in figure 2). It is worth to notice that CO_2 laser have been difficultto be feasible for brazing of aluminium and its alloys. It is detected that the immersion capability is different for various materials i.e. for steels it is 10.6 µm (10%), whereas this value is very low for aluminium alloys at 2% [35].They also analysed the tensile strength of laser brazed aluminum joints of 1 to 3 mm thick specimens and observed tearing in base metal for 1mm thick brazed joint and a 2 and 3 mm thick sheets strength is less with tears in HAZ (see figure 3).The lower in tensile strength of the joints are grounds rigorous heat shock adjacent to the joint interface when the high energy density applied on the joints.

The joining of aluminium to steel in the melted phase is very convoluted attributable to the reaction of elements contained by Fe-Al molten metal. To improve these welds Audi automotive company has been investigated the new technology [37] of using 4.4 KW diode pumped Nd-YAG laser with the fluxless joining of AA6016 with Zn coated DX56D+Z 140MB steel using laser beam with dual spot. In this study they have introduced a concept of process that is divided into two methods such as the joining of the brazing filler and aluminium, and then the liquid aluminium against the zinc coated steel

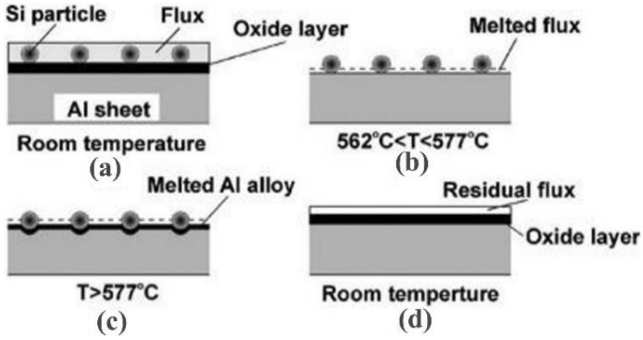

Figure 2 The NOCOLOK® brazing process using Si Flux applied on substrate [34, 36].

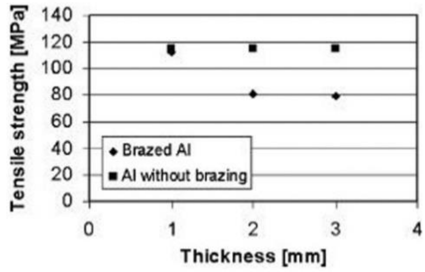

Figure 3 Tensile strength of joints before and after the brazing [34].

To evade the molten state of the Fe. In this technique, during laser process the focus forming module from high YAG-laser technology riven the received laser beam and passage the other beam in relative to that of highest laser beam with diverse approaches and as well as reserves. The second beam laser power varies greatly from ranging between 0 and 60 % for the total created power of the laser. The outcome of the results shows that the preheating of the steel plate using a other laser beam can increase the wetting lengths and a “top head” energy spreading in power beam size of the half circle deludes the development of unbreakable Fe-Al intermetallic phases everywhere areas of liquid steel plate and fusion mode of aluminium. Figure 4 shows the wetting angle formation under dual laser beam welding and laser beam welding with the filler metals. It is observed that the welding temperatures are needed to maintain below 906 ˚C so that the loss of saturating consequence of the zinc cover or indiscretions formation can be avoided. The cross sections of the joints shows that the filler material of aluminium of a dual arrangement of the beams of laser power created the grater wetting lengths by stabilizing the braze-metal molten state liquid for a longer time. It is also noticed that the intermetallics layer for both the Al and zinc based fillers are formed with in the limit, and the maximum limit for hard intermetallic phases thickness denoted that the precarious point of 10 μm [38].The mechanical properties of DX56D+Z 140MB and AA6016 LWB joint produced using Zn based and Al based filler wires exhibits the mechanical strength of the welds will be equal of the strong Al substrate material joints strength when Zn created filler is applied and length of the wetting weld is higher in 3.5 mm. The joints with Zn base filler shows slightly higher hardness in the brazed seam than steel sheet and welds with Al type filler exhibits hardness equal to Al sheet metal (see figure. 5) [37].

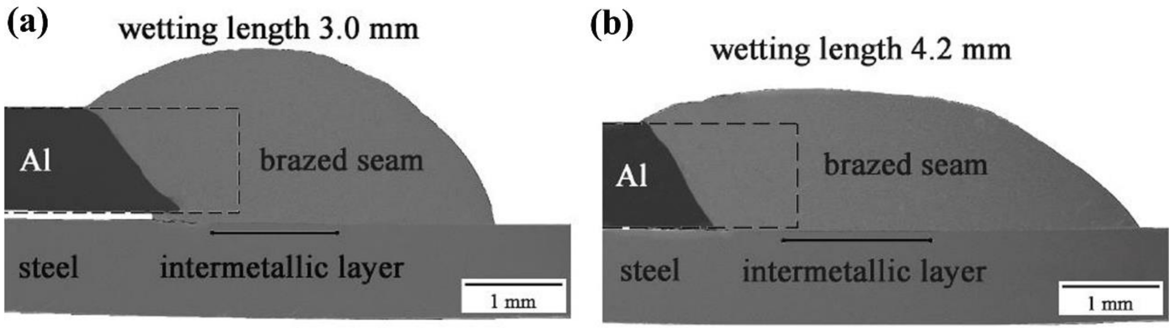

Figure 4 SEM microstructures of the joint cross-sections with $ZnAl_2$ filler material. (a) beam with Single-laser, (b) beam with dual-laser. The indication denotes the boundaries of aluminium plates before welding and the formation of extend intermetallic layer [37].

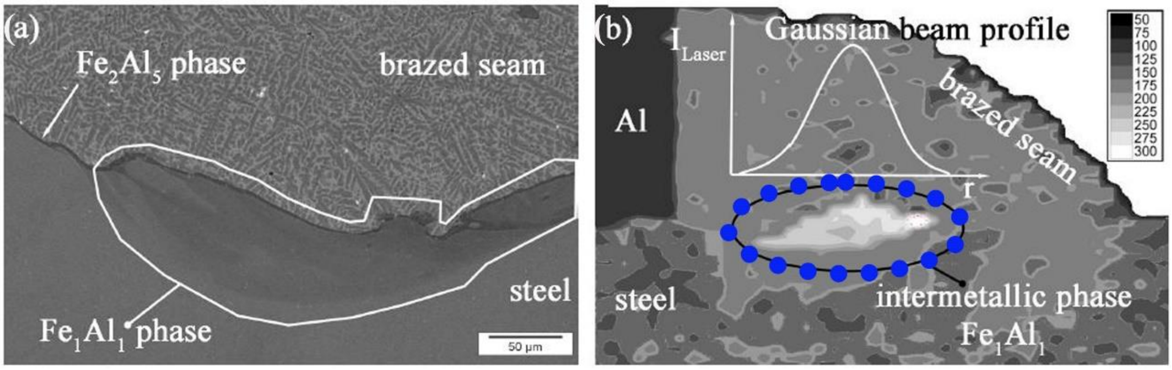

Figure 5 (a) SEM microstructure of the welds using filler alloy of $ZnAl_2$ and showing the brittle phases layers formation in the interface of highest energy input owing to distribution of Gaussian energy defocused optic laser (b) Micro-hardness variation of the welds with blue region indications of brittle Fe-Al phase intermetallics where the location indicated in microstructure [37].

In a while, the similar studies have been conducted by Osaka university, Japan [39], developed a flux less laser brazing technique for steels coated with galvanized (GI and GA steels) using a dual beam brazing. In this study, they have investigated the process by varying laser power of the beam with both powers, distance between them of preheating beam and basis to the substrate metal. The influence of the parameters were analysed on dispersion and wetting characteristics of fusion filler metal of aluminum/galvanized steels lap welds and found the GI steel welds were superior to GA steel joints. The final appearance of the joints was resulted in good bead formation using of positions of beam for preheating. The cause of preheating using beam offset in 2 mm position of the width of the weld bead is likely to minutes lighter compared to the bead width of 0 to 1 mm preheating beam offset positions. It is also worth to mention that the influence of laser beam power for the wetting and spreading possessions which are higher at the 100 W in contrast to 200 W (which are similar to the bead images shown in figure 4).The main advantages of the preheating beam power are studied extensively and found that the range of power beam is 50-100 W; within this range the dependable and appropriate weld bead generation was most likely form which is required for practical applications. Whereas, it was found that the dissemination and wetting behaviour for the filler metal of laser brazing on a GI welds were exhibits much improved results compared to the GA joint. Likewise, the frequent alterations between these materials thought to be the liquefied zinc coating alloys behaviour with the plates of steel, also the angle of weld bead wetting was decreased, because of the extreme heating before actual weld formation.

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The microstructural analysis of the joints shows the development of intermetallics compound phases across the weld interface and the chemical analysis of the elemental mapping distribution at the GA steel and braze filler deposition boundary is illustrated in figure 6. The elements distribution of Al and Si are formed eutectically contained using the molten filler deposition, and the formation of Al and Fe are concentrated for the joint boundary reaction with molten metal layer. The X-ray diffraction studies and its analysis for the joints between GA steel and braze filler interface revealed that the formation of Fe-Al phases such as Fe_2Al_5 and $FeAl_3$(see figure 7).A small amount of Zn was presented on steel interface surface side, it is expecting to be that the Zn plating film were smelted under the beam which is preheated and the laser brazing of material fusion was dampened the top of the steel plate surface sheltered with the fusion metal.The mechanical strength of laser brazed joints revealed that of the maximum fracture asset of galvanised steel plate joints achieved to be of 130 N/mm, joint efficiency was 55% of the substrate of aluminium. In contrast to strength of the fracture for the galvanised steel plate joints of 180 N/mm, joint efficiency was 75% of the substrate of aluminium metal.

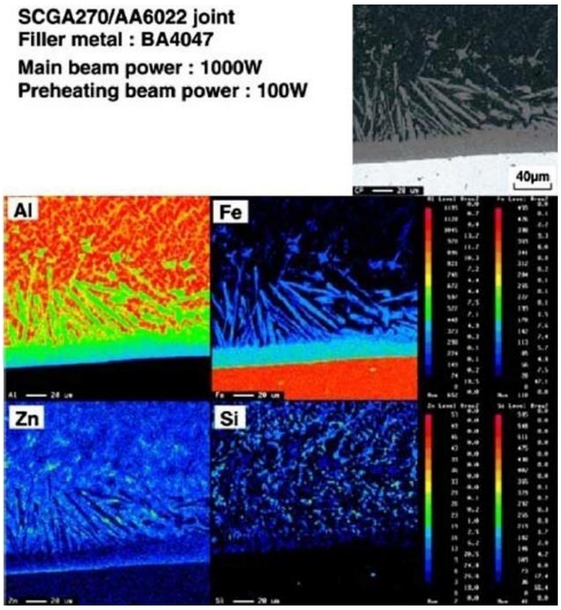

Figure 6 EPMA analysis of the element dispersal in braze zone of galvanized steel joint (0 mm - offset distance) [39].

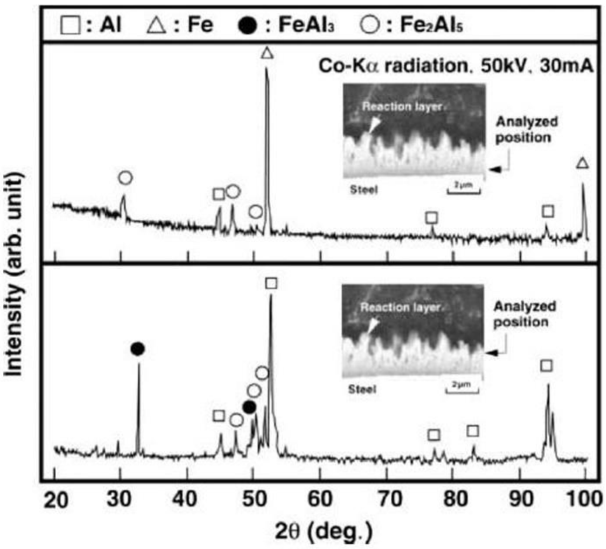

Figure 7 XRD patterns of intermetallic compound phases at steel to braze boundary in galvanized steel joint (0 mm - offset distance) [39].

Jurgen[40] *et al.,* have been studied the fluxless laser brazing process of steel DP 600 to aluminum alloy grades ranging from AA6016 to AA5182 and concluded that the laser power is the key parameter that defines the limits of the process. The mechanical performance of the laser-brazed joints and concluded that using of higher laser beam power and brazing speeds, stronger joints can be achieved. The joint strengths obtained are almost close or even greater than the strength of the weaker base material.

2.2. Effect of laser brazing parameters

The stability of the welding methods and the performance of the joints mechanical properties depend upon the process conditions. Very few studies have been done on the influencing of process parameters on laser brazing and its importance for mass production. The existed literature studies have reported that, in order to achieve the mechanical properties optimization of process parameters are very important [31]. It is reported that the major processing parameters aredefocusing length, beam power, angle of the tilting of laser beam axis, speed of the braze weld, speed of the filler wire, fiber diameter and shaping of the laser beam. Using these process conditions and its related ranges, an optimization technique design of experiments collected for 16 tests [41] assembled. Figure 8 shows the possessions of the different process variables to the mechanical strength of the welds. It is observed from the inspected assortment of the fiber diameter shows the insignificant effect on the strength of the joints. However, the other welding parameters are having a trend of decreasing of the mechanical properties of the joints, as illustrated in figure 8 [31].

Similar studies have been performed by Dharmendra *et al*. [42] on the effect of process parameters like laser power, speed of brazing and speed of wire feed on mechanical properties and thickness of intermetallic layer during laser welding-brazing between dual phase steel and aluminum alloy using Zn type filler. The microstructural analysis of the joints exhibits the intermetallic layer thickness which is changes from 3 to 23 μm in regard to the welding conditions used in the laser brazing experiments. A non-uniform thickness of the intermetallic layer was observed and its thickness is higher at the center of the seam in contrast to edge of the braze seam. The thermal cycle which is in uneven form, presence of reaction layer at interface is mostly be contingent on metallurgical aspects of

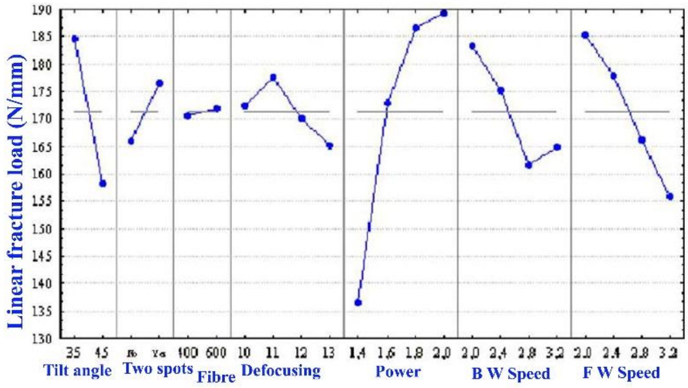

Figure 8 The effect of process parameters on fracture load of the joints [31].

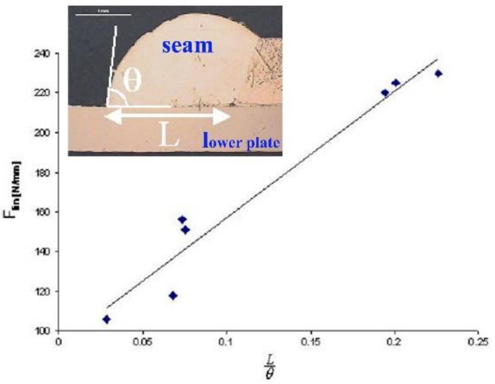

Figure 9 Relation between the geometry of the bead and mechanical strength [31].

such as smelting of the base metals, solidification and spreading of filler metal [42].It is the fact that the fillers which are selected for low melting temperature has less chance to formation of interfacial layer and thus diminish the thermal distortion and advancing of interfacial intermetallic compound layers. The thermal interaction of solid Fe plate and fusion of the deposed wire zone was well-ordered by diffusion mechanism. The interaction layer and its thickness (X) under transmission of electrons control mechanism procedure is provided as $X=K\sqrt{t}$, where K is a constant, and t is the time for diffusion [43].Based on the diffusion mechanism, fusion time appears as the foremost influence to reduce the brittle phases of reaction layer thickness by controlling brazing speed. Figure 10 shows the reaction layer thickness decreased with increase in brazing speed and increasing with increase heat input (see figure 10b). It is observed that the tensile properties confrontation has amplified with the interaction layer thickness up to 8 μm. The highest one reached between 8 to 12 μm and on the go to decrease with additional growth in its thickness (see figure 10c).

To avoid or control the intermetallic compounds formation in the joint interface using thermal process (Laser, MIG, TIG), a new method has been established by Mathieu *et al.* [44]. In this method they were introduced the "hot filler wire" self-possessed of Zn of 85% and Al of 15% (The hot wire concept in details: Filler wire is unwounded by a special equipment of DINSE©device. This setup is needed to connect to a hot wire cause of the equipment type ELEKTROSTA©FC400, it will provide in heat by the Joule effect. The tension can be set to required Volts thus, the possibility of arcing can be avoided when the filler wire going to touch the welding plate [44]). During this study, they have observed that the global geometry of the welds and the development of an interaction compound layer are the function of temperature history during the process. Also they have established what the best

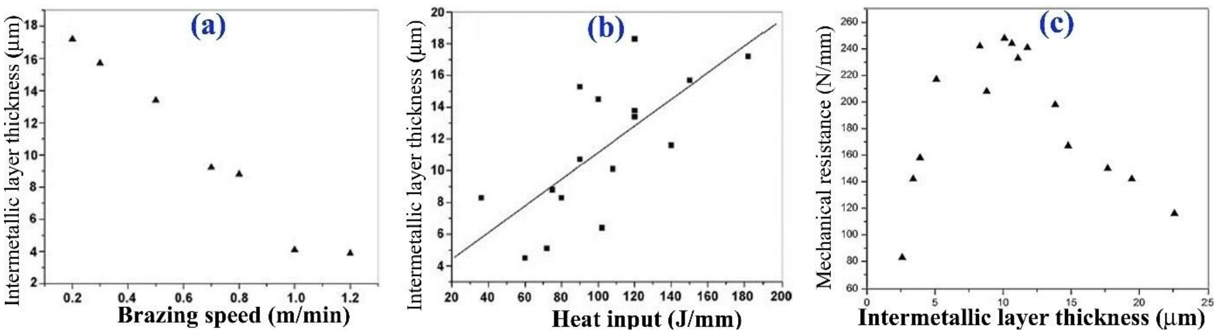

Figure 10 Change in intermetallic compound layer thickness as a purpose of (a) laser brazing speed, (b) Heat input, and (c) change in mechanical resistance (N/mm) of the weldsat the thickness of interaction layer and brittle phases [42].

Process operational conditions and its influence on various results. Thus, the outcome of the results suggested that thermal modelling and temperature or heat input control is compulsory paces for an optimum mechanism of the laser process. This method has been conducted for joining between aluminium and stainless steel using a 4047 filler consumable material which is the alloy contains silicon and aluminium. The reason for selection of this filler was due to their low melting/fusion point since it comprehends Si, because of this it has wide range of applications in laser braze process and hard laser brazing for welding of Al to other materials. The previous literature studies [45, 46], reported that the Si in the filler wire inhibits the metallurgical reactions thereby reduce the formation of fragile (Fe-Al base intermetallics) phases by controlling the diffusion of Fe into the Al [44].

To compare the hot wire brazed joint properties, some of the tests are conducted by using cold wire (cold wire refers to that preheat is not done, it has operated at ambient temperature only). It is observed that the overall performance of the joint characteristics are very poor, the wetting angle of the weld joint on steel sheet side very poor and other sides of the cases there is not observed any interface formation. The tensile tested samples always fracture took place at the weld interface and joint beads was poor, because of the poor adhesion initiates the cracks that are deteriorates the mechanical conflict of the joints. Whereas, the hot wire filler shows good strength of the joints compared to cold wire, and it is also found to the bottom of the weld seam is properly filled (shown in figure 11). Figure 11(b) clearly shows the seam filled with filler and the cohesion phenomena of the seam and aluminum is further widely comparison to cold wire weld seam (see figure 11a). The better joints formations by hot filler are due to its capacity to fill the joint better. It is well known that, the preheated filler wire melts much easier by the laser beam thus resulted in formation of stronger joints.

Laser energy sources and its applications are has become by far the most common and massive use throughout the all kind of technologies. The different applications are depending on the laser energy level and its quality. Li-qun*et al.* [47] have tried to use laser energy in different way that, the stimulus of laser energy involvement method on weld interface features in laser brazing of galvanized steel sheets using Cu type filler metal. The commercial use of a laser beam with CO_2 was shaped into circular shape separate beam spot, a spot of beam with dual-beams and a spot beam with rectangular shape, those which are providing altered density of the laser power in longitudinal dispersals, are exhibited in figure 12 [47]. It is detected that the weld characteristics are different for these three different beams. There is no significant formation of interface layer for the joints made under circular individual laser beam heating. Whereas, a lamellar intermetallic layer can be formed at the weld seam interface, which is provided by the two spots laser beam process. In case of radioactivity of beamof rectangular shape, the intermetallic compounds rarely can produce into the molten filler alloy and contains the tendency of the cellular crystals. Also. It is observed that, using the rectangular beam with long heating time is engaged as heat source of brazing, due to this it is expecting the strengthening of the bottom of the joint with interface reaction. The complete filling of the joint gap can be observed for the hot wire joint configuration compared to cold wire configuration.

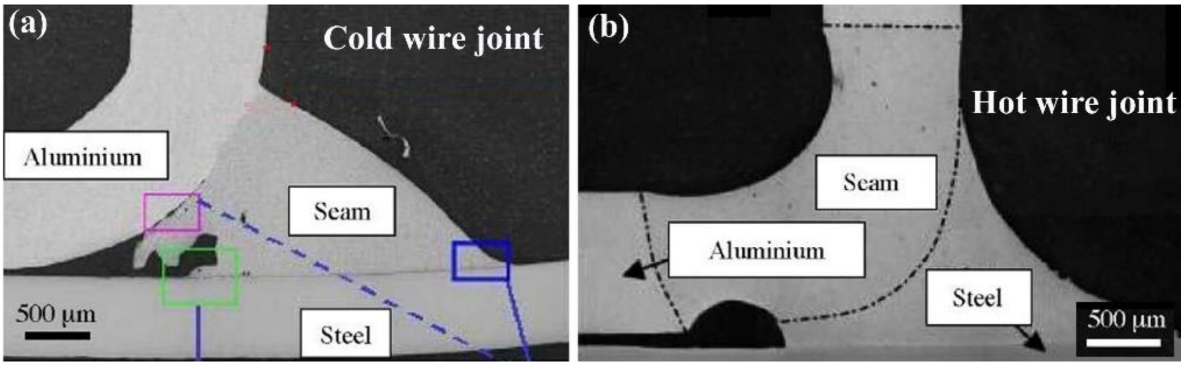

Figure 11 Cross-section showing the steel to aluminium joint (a) cold wire (b) hot wire filler [44].

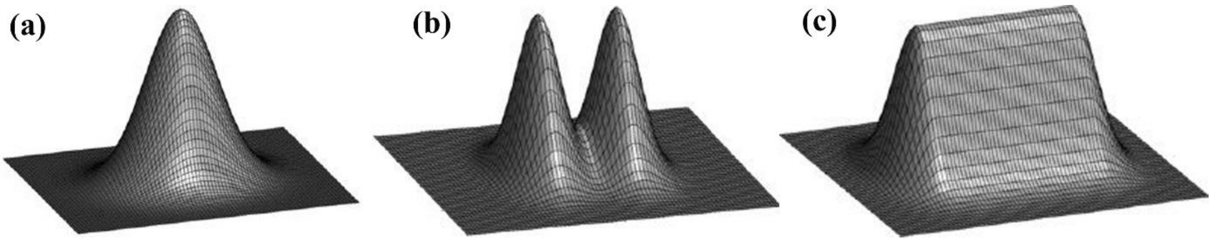

Figure 12 Laser beam power density and its spreading of three different beam methods: (a) circular and individual beam, (b) a spot of dual-beam and (c) rectangular shaped spot [47].

Jurgen *et al.,* [48] studied fluxless laser brazing process of DP 600 steel to Al alloy grades ranging from AA6016 to AA5182 and defines that the laser power is the key parameter that defines the limits of the process. Their studies also found that, the mechanical performance of laser brazed joints exhibits that higher laser power and brazing speeds are resulted in stronger joints. The joint strengths obtained are almost equal or even greater than the strength of the one of the weaker base material.

Chen*et al.,* [49] studied the impact of reaction layer at interface shows the microstructures on initiation of crack and its propagation in Ti-6Al-4V/5A06 Al alloy joint using laser with brazing process. It is observed that the joint at the inadequate and weak of the interfacial reaction, due to more possibilities of initiation of the crack. In the weld seam crack propagates more easily to joint interface/ reaction with associated plane lamella-shaped in contrast to the rough interface with cellular shaped [49]. A continuous reaction layer was in club-shape cause of propitious for the crack initiation and propagation. This layer primes to enhancing in formation of fragile and impulsive crack beginning during the welding process. The interfacial reaction in alloys of dissimilar metals joining is subject to on distribution of thermal cycle and temperatures at the weld interface. However, the formation of thermal cycle during welding can be controlled by process parameters of or it can maintain the heating and cooling conditions for expected thermal cycle. The diffusion behaviour of Si during laser brazing of 5A06 alloy and Ti-6Al-4V with Al-12Si filler wire have been investigated by Chen *et al*. [50].The studies found that the diffusion behaviour of Si plays a vital role in the formation of interfacial reaction compounds. They have also established an important chemical probable calculation model of the ternary alloy constructed on MIEDEMA model. The analysis results showed that the effect of titanium molar segment and Si chemical potential temperature and found the former one is far higher than the later.

The corrosion resistance of dissimilar laser brazed joints of AA6016 with DX56D+Z 140MB using salt spray moist test and micro electrochemical measurements. In both the tests, the corrosion attack in brazed zone has attacked with high undesirable corrosion impending and it started to decompose first. Among these tests, salt spray test results have shown that the alloys have behaved as if they are of without any protection. It is also found that the Zn enriched areas in the weld seam areas

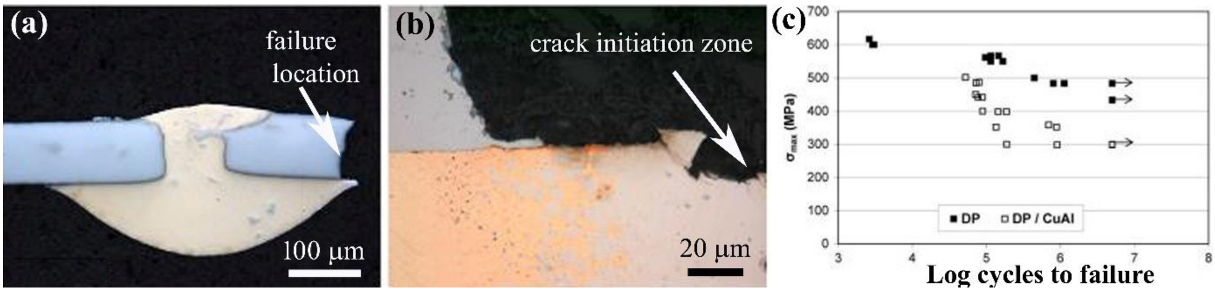

Figure 13 (a) Macrostructures of the fatigue testing of dual phase butt joint, (b) location of the crack initiationand (c) Fatigue test results for lifetime of DP steel and brazed of butt welds for R = 0.1. The signs of the arrows indicated the run-outs [52].

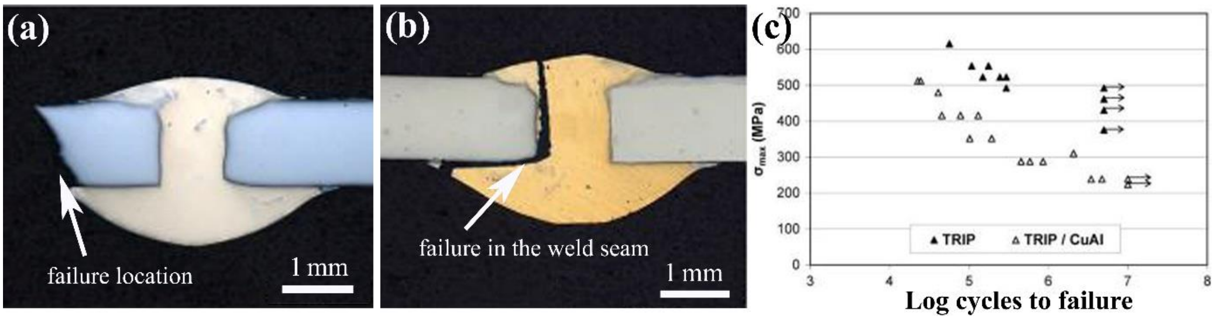

Figure 14 Macrostructures of the fatigue tested fracture locations of the TRIP700 laserbrazed joint at, (a) stress at maximum value of 280 MPa, (b) stress at maximum value of 240 MPa, and (c) Results of fatigue lifetime TRIP700, laserbrazed welds for R = 0.1. The signs of the arrows indicated the run-outs [52].

have exhibits lower corrosion resistance [51]. The formation of intermetallic compounds obeys the rules similarly to steel in the negative sing of the electrons region. Consequently the formation of brittle intermetallic compounds of Fe-aluminides along the interface between steel and brazed joints needs to be circumvented, or else it will lead increased dissolution in seam.

Figure 13 and 14 shows the fatigue properties of dual phase600 laser brazed joints Transformation Induced Plasticity 700 steel welds which are produced with Cu-Al type fillers [52]. The fatigue test results revealed that two failure mechanisms for TRIP700 steel specimens, and single failure mechanism for DP600 steel sheets. The fatigue crack initiation and propagation failure paths of the DP600 and TRIP700 steels are illustrated in figure 13(a, b) and figure 14(a, b) respectively. It is observed that for both the steels at all stress magnitudes, the initialization of fatigue cracks in the brass matrix adjacent to the ends of the weld reinforcement and transmit over the matrix of brass as shown in figures. Further elongation of these cracks reach steel and they will deflect and follow the interface of steel plates and weld seam. The fatigue life of the steel joints of DP600 and TRIP700 are shown in in figure 13(a, b) and figure 14(a, b) respectively. It is observed that the maximum stress of the joints reaches beyond 280MPa, fatigue test cracks begins to initiate and spread over the steel surfaces. In case of TRIP700 steel joints when the stress is less than 280MPa, the cracks are continuously nurture lengthwise the weld interface up to they spread to the ends of the steel and then crack grows abrupt to the applied load direction over the braze metal [52]. Microstructural analysis reveals the removing of brass segment instinctively could advance the results of fatigue strength of the span of life time of the brazed joints in place of the crack formation in the brass segment and it resolve be occur. It is also found the weld bead characteristics from the analysing of microscopic examination, a small size wreckages of the reaction layer was fluctuating around the molten braze seam, it is demonstrating that the interface layer can sustain the temperatures of the weld beads touched for the period of brazing.

The intermetallic phases of $AlMn_xSi_y$ have melting temperatures around 900-1000 °C [53] and subsequently they will sustain the brazing process temperature.

Ungers *et al.* [54], Fecker *et al.* [55] and Frank *et al.*[56]have been developed an online quality monitoring system in order to detect weld seam imperfections and defects such as pores, surface irregularities, cavities, improper wetting, joint discontinuities, etc. In order to monitor the quality system, an optical system of CPC system (Coaxial process control) is used, which has two cameras operating at different spectral ranges. One is high speed camera of CMOS (complementary Metal Oxide semiconductor) and the other one is NIR camera (Near Infra-Red) observing the process in a coaxial arrangement. The developed optical system is able to give the necessary information for the measuring of process operating parameters such as melt pool length, brazing velocity and the position of the brazing wire by the CMOS camera. The weld seam imperfections can be able to detect from the images of thermal radiation attains from NIR camera.

Chen *et al.*[57]have been made an attempt to enhance the non-homogeneity of reactions in interface during laser brazing of Ti-6Al-4V alloy to aluminum alloys (5A06) by using constant energy

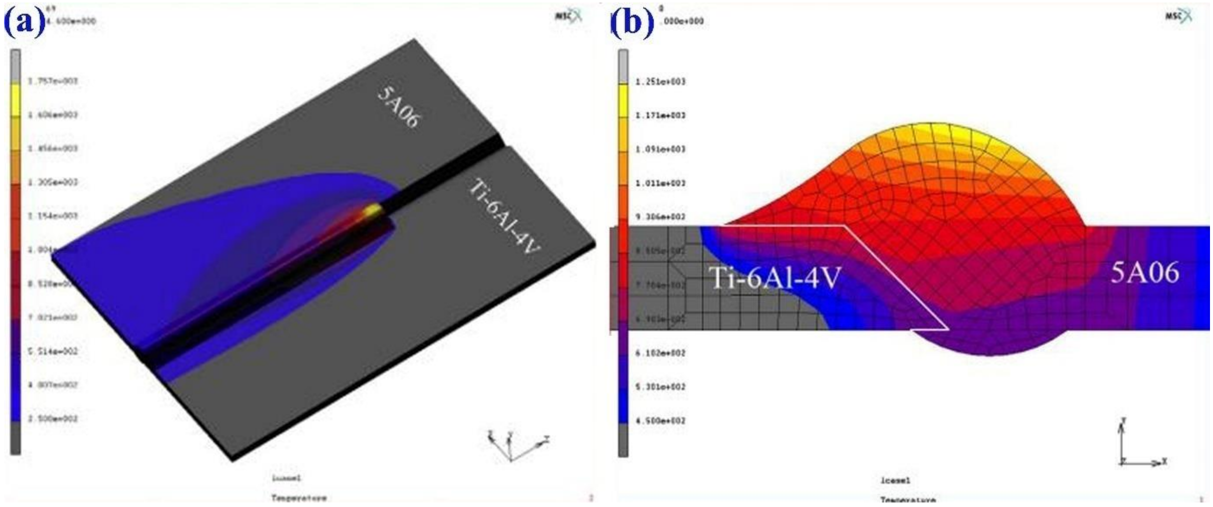

Figure 15 Simulation results shows the temperature field of laser brazing weldsthrough circular beam spot, (a) top view of the weld seam, (b) joint crosssections[57].

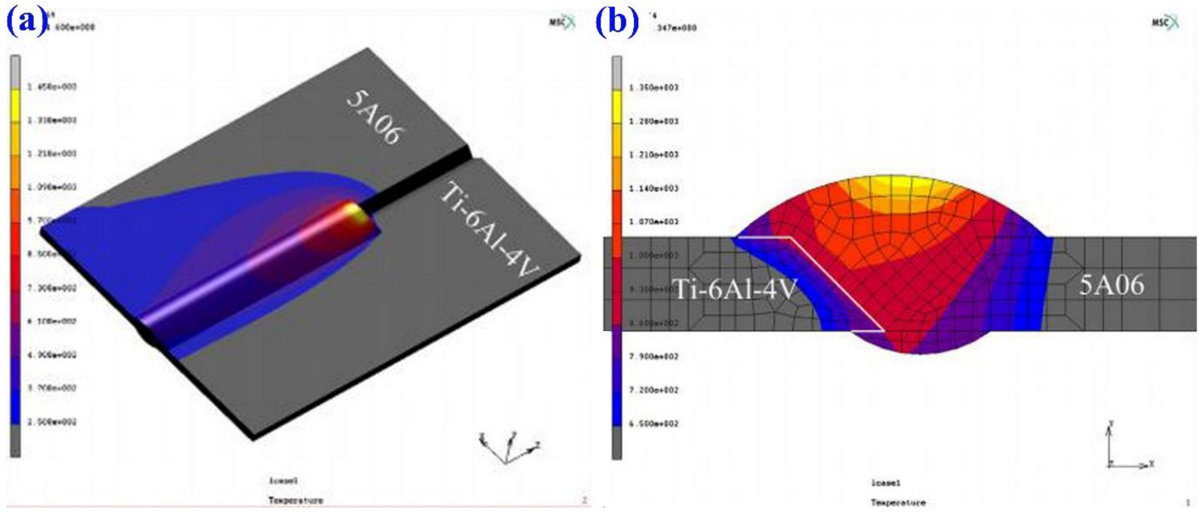

Figure 16 Simulation results shows the temperature field of laser brazing welds by rectangular beam spot, (a) seam top view, (b) joint crosssections [57].

spreading of laser energy beam with the suitable weld groove shapes. They also have successfully made an attempt to advance the non-homogeneity and relative energy distribution of laser beam. FEM, numerical modelling and simulation and the results of experimental validation process was conducted to examine the influence of non-homogeneity of interfacial reaction layer with the circular and rectangular beam mode, are shown in figure 15 and figure 16, respectively. From their investigations they have concluded that the rectangular spot laser will improve the homogeneity of the interfacial layer in comparison with circular spot laser. The aggregate values tensile strength of the welds failed in the weld track is 278 MPa, it is considerably greater value compared to incomplete interface or in the defect formation of porosity [57]. The joints tensile strength variations for broken weld tracks are lesser compared to others, because of the formation of welds fracture at weld seam; it has stable mechanical resistant properties. Song *et al.*[58] have been investigated the influence of laser offset distance for mechanical properties and interfacial microstructure of the A6061 to TiAl4V two different materials combined joint produced without filler metal and without groove formation. The results exhibited that increase in laser offset related to the joints tensile strength, and it is increases owing to the reducing of the interfacial intermeallic layer thickness.Zhou *et al*. [59] have been reported the influence of laser beams offset distance on combine process of laser welding brazing of dissimilar alloys of brass and Al. The results of it showed the defect free welds when the laser beam was irradiated on the aluminum side, whereas, there are defects formation such as cracks and lack of penetration which of the laser weld beam was concentrated over the brass plate.

Tan *et al*. [60] reported the consequence of process heat input on microstructural and metallurgical properties for the laser welds of the 201 ASS and AZ31B Mg alloy joint. It is observed that the metallurgical bonding achieved by the formation of ultra-thin reaction product at the weld interface with a thickness varying from 0.5 to 3μm, and it is increasing slowly with increasing heat input. To obtain these results, Fact sage thermo chemical software was used to evaluate the reaction products thermodynamic stability which are generated along the weld interface in the temperature range of 400°Cto 1100°C and attained better understanding of microstructural characteristics at different compositions and temperatures.

Mittelstadt *et al*. [61] have reported on two spots beam laser welding brazing of very thin DC04 steel sheet for transportation industry applications by Cu-based filler alloys. It is found that the activation of the substrate layers by preheating is compulsory to tolerate required wetting and spreading by the selected braze filler metal.

Gatzen *et al*. [62] have studied the wetting behavior and weld metal solidification characteristics of Al on steel surfaces with Zn coated in laser welding and brazing. It is understood that the proper breakage of an oxide layer is compulsory to starts dispersion on surfaces of the Zn coated steels.

Reimann *et al*. [63] investigated the influence of different Zn coatings such as electro galvanized, hot dip galvanized, etc. on laser brazing of galvanized steel. Mechanical properties also changes like other process [64-68]. They have studied the emission of spatter, evaporation behaviour, and temperature distribution of the Zn. It is identified that the optical properties resulting the temperature distribution as a crucial factor for the Zn evaporation and the evasion of spatter during the process.

3. Conclusions

According to investigations of laser brazing of various materials for automotive applications and its importance in mass production, and recent research reports on implementation of this process studied in detail. Laser brazing process was widely used in joining of various materials combinations and encountered the problems raised during laser brazing. Even though laser brazing has been developed, still it has some draw back sin producing high quality joints. The research has been done in the areas like development of different optical systems for laser brazing, online quality monitoring system, wetting behaviour of filler materials on base materials like aluminium, galvanized steel, titanium etc. The studies on optimization of process parameters like brazing speed, laser heat input, wire feed speed, focusing lengths are influencing the microstructural, mechanical and corrosion properties of the laser brazed joints of different material combinations. The formation of intermetallic compounds layer, distortion, thermal effects are can be reduced or completely avoided by using laser brazing process. Many studies showed the best joining process for thin sheets especially for the zinc coated steel steels are joined with less problems compared to other thermal processes. The advances in laser beam modes also have shown dramatically changes in mechanical and microstructural properties of the welded joints when the laser beams are in circular and rectangular modes. The recent developments in different laser energy beams of diode lasers and tri-focal lasers are results in more efficiently and producing of high quality joints. Finite element modelling, numerical simulation techniques and experimental validation analysis exhibits effect of non-homogeneity of interfacial reaction layer with the circular and rectangular beam mode on mechanical properties of the joints. The rectangular spot laser will improve the homogeneity of the interfacial layer in comparison with circular spot laser. Laser heat input effect on intermetallic compounds formation reveals the metallurgical bonding of ultra-thin reaction product at the weld interface with a thickness varying from 0.5 to 3 μm, and it is increasing slowly with increasing heat input.

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