

# SYNAGIC CONTROLLED LASER ROLL BONDING OF DISSIMILAR METAL JOINTS

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## ABSTRACT

Laser roll bonding is a new process involving simultaneous laser heating and roll bonding. In this work, it was used to join dissimilar metal sheets of mild steel (SPCC) and aluminum A1050 and its alloy A5052, as this combination is used in industry to reduce weight of structural parts. The process parameters like laser power, roll pressure and travel speed were varied and synagic controlled to get more ductile intermetallic compounds at the interface. Strength of the joints was tested by tensile shear test and formability was tested by Erichsen cupping test. In tensile shear test, the laser bonded joint was broken in base metal of carbon steel. The results showed that the strength of joint increases with the decrease in the interface layer thickness, but in the absence of interface layer, no bond is formed. The shear strength of laser roll bonded specimen ranged between 21.8 and 55.9MPa. Erichson value (cupping-depth) and shear-strength are strongly affected by laser heat-input and roll pressure. Pulsed laser power, pulsing travel and roll pressure are effective to get better intermetallic compounds and joint strength. The basic data for synagic control were obtained from present experimental results.

**KEY WORDS** : Dissimilar Metals, Laser Roll Bonding, Pulsed laser, Intermetallic Compounds, Steel to Aluminum

## 1. Introduction

The new automobile industry has a continuous requirement for weight reduction to increase efficiency and reduce air pollution. One way suggested is the use of the combined structure consisting of Aluminum alloy and steel sheet. Therefore, it is necessary to join these dissimilar metals together for different shapes in large continuous production suitable for the modern automobile industry. Attempts of using resistance spot welding with inserts for this purpose have been already made [1]. Major problem appeared during joining these dissimilar metals are the formation of intermetallic brittle compounds like FeAl<sub>3</sub> & Fe<sub>2</sub>Al<sub>5</sub> in the interface layer. It has been reported that if the thickness of the intermetallic compound layer is limited below 10 $\mu$ m, the joint strength is improved [2] In the present work CW and pulsed CO<sub>2</sub> laser welding were used, CW CO<sub>2</sub> laser were used to weld the steel sheet with aluminum A5052, and pulsed CO<sub>2</sub> laser used to weld the pure aluminum A1050. Using of laser

beam welding of steel and aluminum were also reported [3]. An attempt is made to identify and estimate the thickness of the intermetallic compounds after diffusion bonding with different conditions of pressure, travel speed, and laser power. Due to laser heating, the material experiences fast heating and cooling rates. It has been found that the formation of the brittle compounds takes place by diffusion process, which involves slow heating and cooling rates. Therefore, a process combining laser heating and roll bonding is suggested. It is intended that the laser heating of steel in such a way that the interface reaches the temperature sufficient to form the bond while it being pressed. It was aimed to control the joining process by varying laser power, travel speed, and roll pressure so that to promote the formation of brittle intermetallic compounds in the interface layer. The joint strength and formability were determined by tensile shear test and Erichsen test respectively.

## 2. Experimental Procedure

### 2.1 Material used

The commercial materials used in automobile industry for car body are low carbon steel and

aluminum alloys. The sheet thickness for both types aluminum A5052 and A1050 is 1mm, and for steel sheet is 0.5mm used in present work. The chemical composition is shown in Table 1.

Table 1 Chemical composition of materials used (in mass %)

Alloy	Mg	Cr	Si	Fe	Cu	Mn	Zn	Others
A1050	0.05max	-----	0.25max	0.4max	0.05max	0.05max	0.05max	0.03
A5052	2.5	0.23	0.25max	0.4max	0.1max	0.1max	0.1max	0.05

SPCC steel	C	Mn	P	S
	0.12 max	0.5 max	0.04 max	0.045 max

## 2.2 Laser Roll Bonding

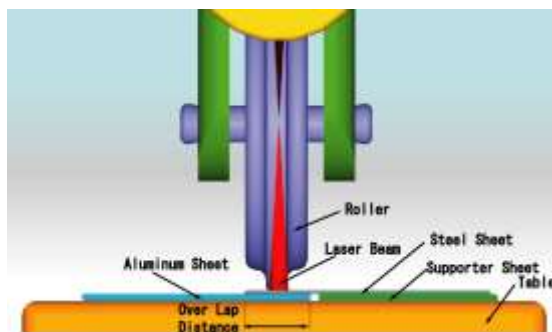
A lap joint was used to combine the steel sheet with the aluminum alloys as shown in *Figure (1)-a*, the steel was placed on the top of the aluminum in order to absorb the heat from the incident laser beam without melting and conduct the heat to the interface. The over lap was 9mm, and the Gaussian beam was defocused to give elliptical spot of 2.5 mm minor and 3.5mm major diameter on the steel surface.

In order to heat the interface between the steel and aluminum to a suitable temperature by laser beam, and apply pressure to this interface at the right time, the laser roll-bonding fixture used in the present work is made as shown in *Figure (1)-b*.

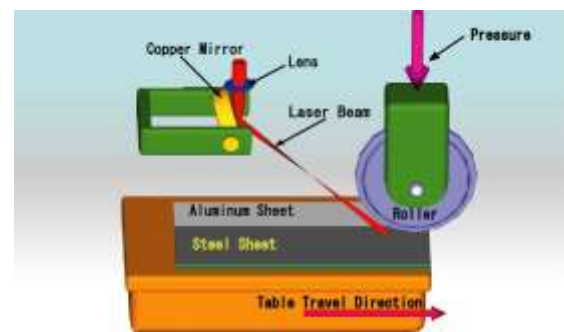
A spring is used to press the joint against the table through the roll; this pressure can be determined by the spring deflection. Prior to joining, the faying surfaces of both sheets were

cleaned by using the suitable way, for Aluminum sheets, ultrasonic cleaning was applied to remove the hard aluminum oxide film, then it was merged with brazing flux ( $KaF_4:K_2AlF_5.H_2O$ ) to prevent further oxidation and remove any if exist.

Laser Roll Bonding with varying travel speed, laser power, and roll pressure were carried out. The Joints were cut transversely to observe the macro-structure and microstructure. The same were used to identify and estimate the intermetallic compounds through the interface layer by EPMA with WDX method. Based on the EPMA results the thickness of the interface layer was divided into ductile compounds ( $FeAl+Fe_3Al$ ) and brittle compounds thickness ( $FeAl_3+Fe_2Al_5$ ). For estimating the strength and formability of the joints, three samples were prepared for tensile shear test and one specimen for Erichsen test.



(a) Clamping setup



(b) Laser Roll Bonding process

Figure( 1) Schematic drawing of Laser Roll Bonding

## 3. Experimental results and discussions

The main purpose of using CO<sub>2</sub> Laser Roll welding is to achieve fast heating and fast cooling, which may suppress the formation of the brittle intermetallic compounds. To increase the

possibility of formation of the ductile intermetallic compounds ( $FeAl+Fe_3Al$ ), the interface temperature should be in the range 1200°-1300°C as shown in *Figure (2)* for Iron-Aluminum phase diagram. Temperature is the most essential

variable since it, together with pressure, determine the extent of contact area during diffusion bonding and it alone determine the rate of diffusion that governs void elimination.

Changing pressure values with interface temperature (by varying the laser power or travel speed), we can control the interface layer thickness until the optimum is reached, in which the brittle compounds layer thickness will be minimum and the ductile one will be maximum. In addition to these parameters, a pulsed laser welding is used in welding the pure aluminum A1050, which enable us for more control of the heating and cooling rates by changing the pulse.

As the interface layer temperature reaches the required range, a thin surface region of aluminum in the macrostructure in figure (3). And typical microstructures of laser roll bonding joints are shown in Figure (4).

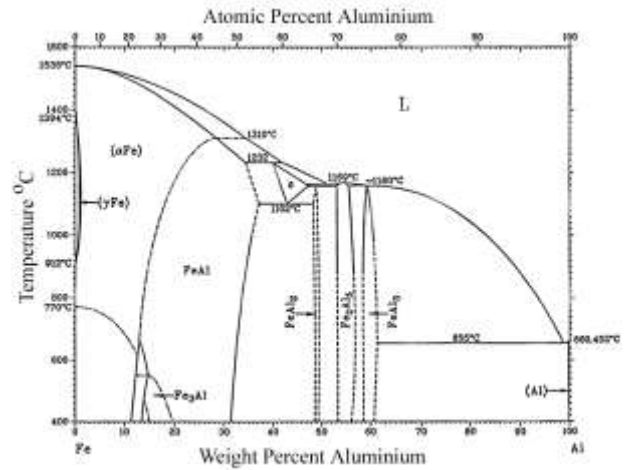
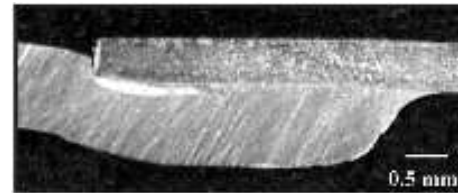


Figure (2) Fe-Al Phase Diagram

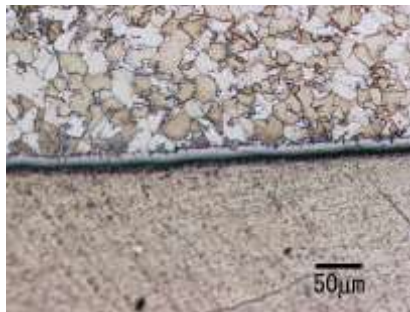


1.5kW-1.5m/min-150MPa  
(a) SPCC-A1050

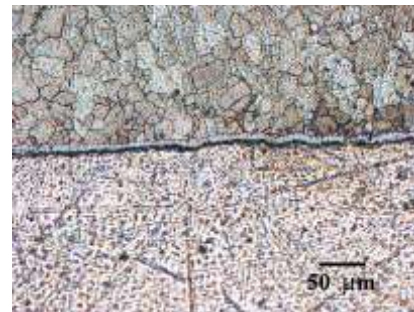


1.5kW-2.2m/min-202MPa  
(b) SPCC-A5052

Figure (3) Macrostructure Samples



1.5kW-150MPa-4.0m/min  
(a) SPCC-A1050



1.5kW-150MPa-2.0m/min  
(b) SPCC-A5052

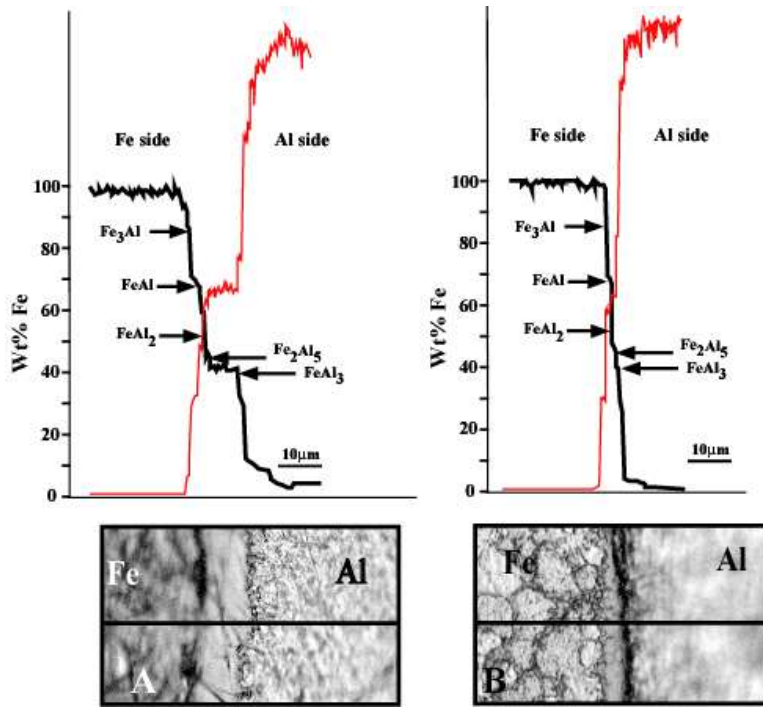
Figure (4) Macrostructure Specimens

The width of intermetallic compound layer shown were less than  $10 \mu m$  and homogeneous.

The interface layer was analyzed by using EPMA method; the EPMA results in Figure (5) for A5052 show the existence of the ductile compound on the steel side and brittle compound on the aluminum side for a constant pressure, and laser power for two travel speeds. Figure (6) show the fraction thickness for both ductile and brittle compounds through the interface layer is changing with travel

speed. In general, for a constant laser power and pressure, starting with a low speed, will offer a longer time for the diffusion process to take place in which in turn produces a thicker layer with higher percentage of the brittle compounds.

With increasing the travel speed the percentage thickness of the ductile compounds increases from 23% to 51% for A5052 alloy and from 7.6% to 40.6% for A1050. The reason is related to controlling the diffusion rate by changing heating and cooling rates with travel speed.



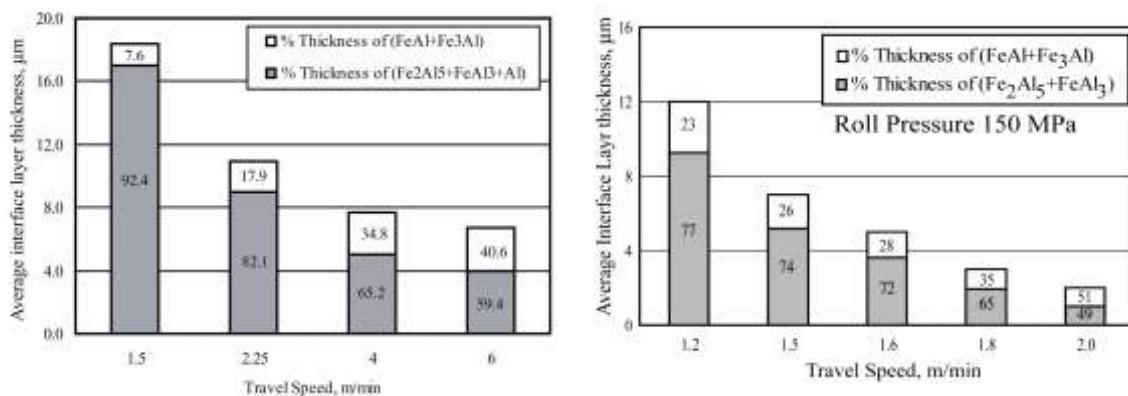
(a) 1.5kW-150MPa-1.2m/min (b) 1.5kW-150MPa-2.0m/min  
 Figure (5) EPMA analysis for SPCC-A5052

In this experiment, different laser powers and roll pressures were used to study their effect on the interface compounds. Increasing the power has the same effect of decreasing the speed, but if laser power reaches to high values, it will cause melting of the steel sheet, and if it reaches to low values, the heat input may not be sufficient to produce bond. As for the pressure, it is necessary for increasing the contact area directly after heating for a short time to allow diffusion process to take place, and help in increasing the cooling rate of the joint by heat conduction.

Figure (7) shows the relation between tensile shear strength and interface layer thickness with travel speed. By increasing the travel speed, the

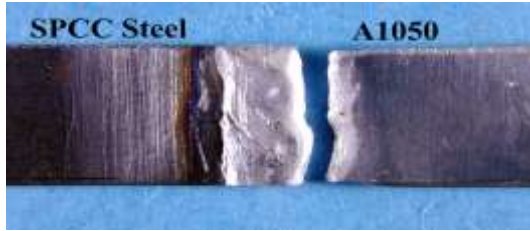
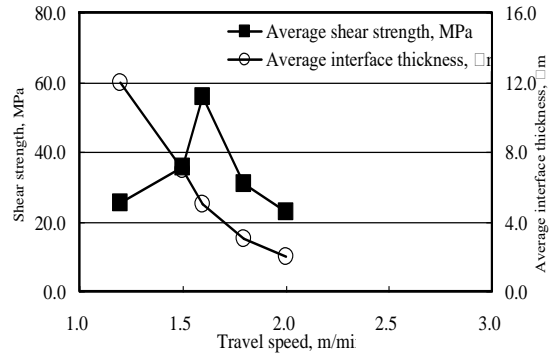
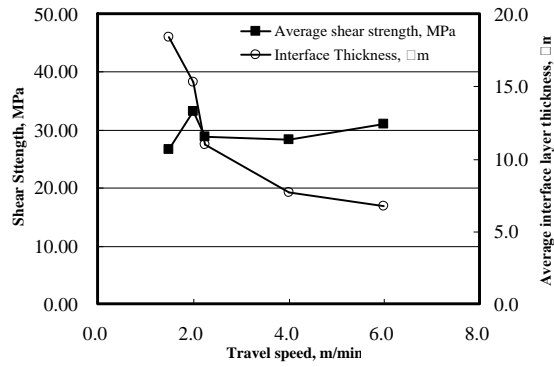
interface layer thickness decreases, at the same time shear strength increases up to 33.1MPa for A1050 and to 55.9MPa for A5052. Although in higher speeds, the percentage of ductile compounds is relatively high, the shear strength drops down for fast travel speed, owing to insufficient temperature due to the lack of heat energy at the interface layer.

To detect the formability of these joints, which it is a major characteristic of the sheets used in automobile industry, Erichsen test was carried out and evaluated with different speeds as shown in figure (8). The cupping height increases with speed until it reaches a maximum value then starts to decrease



(a) SPCC- A1050 (1.5kW-150MPa) (b) SPCC- A5052 (1.5kW-150MPa)

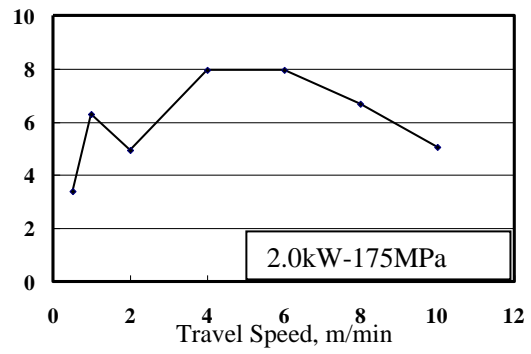
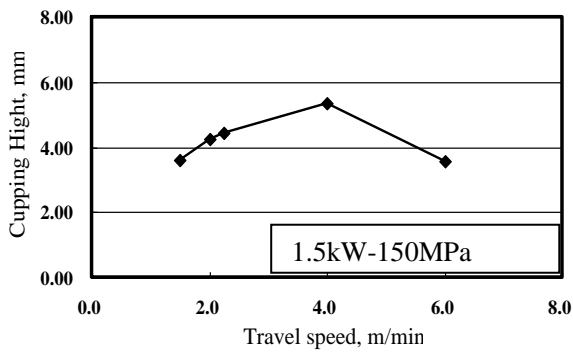
Figure (6) Composition of IMC in the interface layer



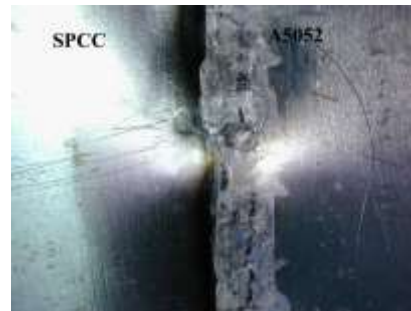
(a) SPCC- A1050

(b) SPCC-A5052

Figure (7) Effect of travel speed on shear strength



1.5kW-150MPa-1.5m/min



2.0kW-175MPa-2.0m/min

Figure (8) Results of Erichsen Test performed on laser roll bonded joints

almost in the same manner with shear strength analysis. The maximum cupping value is related to the existence of the optimum thickness of the

interface layer, which is responsible of relatively high percentage of ductile compounds with a sufficient heat for satisfactory strong bonding.

## 4. Conclusions

1. It is possible to joint the aluminum alloys to steel by using laser roll bonding. Moreover, by controlling the parameters such as laser power, travel speed, roll pressure and pulse; we can get 55.9MPa shear strength for A5052 and about 30MPa for A1050.
2. With good contact of the faying surfaces by roll pressure, heat conduction can be accomplished from steel to the aluminum. Laser heating provides high energy density in the beam spot and rapid heating and cooling cycle. Therefore, diffusion bonding takes a place for a short period because of the short thermal cycle.
3. For both joints made from A1050 and A5052 aluminum alloys with SPCC steel after laser roll bonding, the EPMA analysis shows that interface layer consist of brittle intermetallic compounds –  $\text{FeAl}_3$  and  $\text{Fe}_2\text{Al}_5$  – on aluminum side and ductile one –  $\text{FeAl}$  and  $\text{Fe}_3\text{Al}$  - on the steel side. As the travel speed increased, the total thickness of the interface layer decreased with increasing of the thickness of ductile compounds.

## 5. Acknowledgement

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## 6. Rerences

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