Fluxless Laser Brazing of Aluminium to Steel

Authors

Jurgen Vrenken¹, Cierick Goos¹, Tony van der Veldt¹, Wolfgang Braunschweig²

¹ Corus RD&T, IJmuiden, The Netherlands
² Aleris Rolled & Extruded Products – Europe, Koblenz, Germany

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Jurgen Vrenken¹, Cierick Goos¹, Tony van der Veldt¹, Wolfgang Braunschweig²

¹ Corus RD&T, IJmuiden, The Netherlands
   (contact: jurgen.vrenken@corusgroup.com)
² Aleris Rolled & Extruded Products – Europe, Koblenz, Germany
   (contact: wolfgang.braunschweig@aleris.com)

Weight reduction in order to reduce CO₂ emissions remains one of the main drivers in the automotive industry. Inevitably this will result in multi-material designs where the most appropriate material is selected for each part. A key enabler for such a multi-material design is joining. In conjunction with Aleris, Corus RD&T has developed Fluxless Laser Brazing, a laser process capable of joining steel to aluminium without requiring a flux. Favourable results have been obtained on a range of material combinations, both when it comes to joint strength, process speed and the thickness of the intermetallic layer. All in all, this process appears very well suited for use in automotive applications.

1 Introduction

Reducing weight in order to reduce CO₂ emissions remains one of the main drivers in the global automotive industry, which is balanced with the need to keep manufacturing costs down. Inevitably this will result in multi-material designs where the most appropriate material is selected for each part. This is illustrated by the outcome of the SuperLightCar project, a large European project with 38 partners from across Europe. The project, now in its final stage, successfully achieved its target of reducing the weight of the Body-in-White (BIW) of a current mass-produced vehicle with 30%, without compromising its manufacturability (Figure 1).

Joining is a key enabler for such a multi-material design. In conjunction with Aleris, Corus RD&T has been working on a robust joining process to join aluminium to steel. This has led to the development of Fluxless Laser Brazing, a laser based process requiring single sided access only and capable of joining the most commonly used automotive steel and aluminium grades without requiring a flux.

Figure 1: The multi-material BIW developed within the SuperLightCar project
1.1 Joining steel to aluminium with a thermal joining process

In order to create a proper joint between steel and aluminium with laser brazing, or with any other thermal joining process, two problems need to be addressed.

The formation of intermetallic phases

Above a certain temperature intermetallics are formed when aluminium and steel are into contact. As can be deduced from the phase diagram (Figure 2), possible intermetallics are: Fe$_3$Al, FeAl, FeAl$_2$, Fe$_2$Al$_5$, FeAl$_3$. In general these phases are hard and brittle. The thinner the intermetallic layer, the better the joint properties. Good mechanical properties have been reported when the thickness of the intermetallic layer remains below 3 µm [1,2,3].

The presence of an oxide layer on the aluminium

Aluminium is covered with a natural and protective oxide layer. Without special measures this oxide layer will remain intact, even when the aluminium is melted. An intact oxide layer will keep the aluminium from wetting the steel and as such the creation of a joint (Figure 3A). An often used approach to overcome this problem is to use a flux, which is a chemical that is applied onto the surface of the aluminium base material and when heated reacts with the oxide layer and breaks it up. The molten aluminium is now free to wet the steel and to form a joint (Figure 3B). A filler wire may
be used in this process, but is not essential.

In the Fluxless Laser Brazing approach an aluminium based filler wire is essential. A 'normal' weld is made between the filler wire and the aluminium substrate (Figure 4). During that process the aluminium oxide layer that is present on both the filler wire and the aluminium substrate will be broken up and will cease to be a problem. Subsequently, the molten filler material wets the steel and creates a brazed joint on the steel side.

1.2 Fluxless versus flux based laser brazing

Fluxless laser Brazing has two distinct advantages compared to a process that does require a flux:

No need to apply and remove a flux.

Obviously, when using a flux it needs to be applied. Although 'non corrosive' fluxes are available, it may still be necessary to remove the remaining flux after joining, for instance because the flux may not be compatible with automotive cleaning sections and/or painting lines. As a result, the use of a flux requires at least one but possibly two additional process steps.

Joining of Mg containing aluminium (5xxx) alloys.

Many fluxes tend to react preferentially with Mg, making the flux unavailable for their actual goal, the breaking up of the aluminium oxide layer. If that is the case, only low Mg containing aluminium alloys (as 6xxx alloys) can be joined and alloys with a high Mg content (as 5xxx alloys) cannot.

In the case of the Fluxless Laser Brazing process this problem simply does not exist and, as will be shown later, both 5xxx and 6xxx aluminium alloys can be joined.

2 Technical background

2.1 Experimental set up

The experiments have been performed with a 4.5 kW diode-pumped Nd:YAG laser (Trumpf HLD 4506) integrated on a Staubli RX170B HP robot. In Table 1 an overview is given of both the standard settings and the variations used during the investigation. Although the Fluxless Laser Brazing process is very well capable of joining steel to aluminium in an overlap configuration (Figure 5), the bulk of our work has been performed using a 'T-joint' configuration (Figure 4) and this paper will

<table>
<thead>
<tr>
<th><strong>Table 1: Overview of process settings</strong></th>
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<tbody>
<tr>
<td><strong>Laser power</strong></td>
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<td><strong>Travel speed</strong></td>
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<tr>
<td><strong>Filler wire</strong></td>
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<tr>
<td><strong>Filler wire diameter</strong></td>
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<tr>
<td><strong>Filler wire speed</strong></td>
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<tr>
<td><strong>Shielding gas</strong></td>
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<tr>
<td><strong>Spot size</strong></td>
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<tr>
<td><strong>Spot position</strong></td>
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<td><strong>Working head</strong></td>
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</table>
focus on those results only.

Joints were prepared over a length of 45 cm from which 25 mm wide specimens were cut. These specimens were tensile tested using a Schenck tensile tester. The results are expressed in N/mm, the strength of the specimen divided by its width.

2.2 Materials

A range of materials have been evaluated in the course of the investigation; steel grades ranging from forming steels to DP600 and aluminium grades ranging from AA6016 to AA5182, the latter having a 4.9% magnesium content. However, the bulk of the work has been performed using 0.7 mm thick BH180GI, a bake hardenable hot dip galvanised steel (EN10292), and 1.15 mm thick Superlite® 200 (AA6016). An overview of the most important properties of these materials is given in Table 2.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (mm)</th>
<th>Rp (MPa)</th>
<th>Rm (MPa)</th>
<th>Tensile strength N/mm</th>
<th>Zinc coating weight (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA6016 (Superlite® 200)</td>
<td>1.1</td>
<td>142</td>
<td>245</td>
<td>270</td>
<td>-</td>
</tr>
<tr>
<td>EN10292 (BH180GI)</td>
<td>0.7</td>
<td>219</td>
<td>321</td>
<td>225</td>
<td>60</td>
</tr>
</tbody>
</table>

* Strength of the material per unit of width (= Rm * thickness)

3 Results

3.1 Observed trends at constant brazing speed

In this paragraph the observed trends when using a constant brazing speed will be discussed. This will be done using results at a brazing speed of 3 m/min, but at other speeds the observed trends were very much the same.

3.1.1 Optimising the strength at constant brazing speed

In Figure 6 an overview is given of the results obtained with a brazing speed of 3 m/min. A maximum strength of 207 N/mm was achieved when using a filler wire speed of 10 m/min. This strength is about 90% of the strength of the steel (225 N/mm), the weaker of the two base materials (Table 2). Figure 6 can also be used to explain how the strength of the joints was optimised. The laser power and brazing speed were chosen and were kept constant during a series of experiments in which the filler wire speed was gradually increased. Increasing the amount of filler material has two effects:
• The amount of material in the joint increases, which tends to increase the strength of the joint.

• Because more filler material needs to be melted, the temperature in the weld pool decreases, reducing the intermetallic layer thickness, which also tends to increase the strength of the joint.

Indeed, in most cases the strength of the joints increased with increasing filler wire speed, up to a certain point after which a sharp drop in strength was observed. At that point the amount of filler material is simply larger than the laser is able to melt, making the wire feeding and consequently the whole brazing process unstable.

The above described procedure also explains the advantage a laser based process has over, for instance, an arc welding process. Laser power, travel speed and filler wire speed can be chosen completely independently making it possible to select the most appropriate filler wire speed for any combination of laser power and brazing speed.

3.1.2 Microscopy

In Figure 7 a cross section is shows of the strongest specimen that was manufactured at a brazing speed of 3 m/min. At 3 locations the thickness of the intermetallic layer was determined. The thickness of the intermetallic layer depends somewhat on the location in the joint and reaches its maximum near location 2 (Figure 7). Having said that, in all cases the thickness is below 1 µm and in some areas the intermetallic layer is even hardly distinguishable at all.

The chemical composition of the intermetallic layer at location 2 was determined using the EDX detector of a Scanning Electron Microscope (Figure 8). Iron, aluminium and silicon were detected, but although the steel substrate was galvanised, no traces of zinc were found at the aluminium-steel interface, which indicates that the joint is truly an aluminium-steel joint.
Figure 7: Cross section of the strongest joint prepared at a brazing speed of 3 m/min. (Figure 6), showing the intermetallic layer at 3 locations.

Figure 8: Chemical composition of the intermetallic layer (in location 2) of the same specimen as shown in Figure 7.
3.2 Brazing speed versus strength

Figure 9: Strength levels achieved at different brazing speeds, with corresponding filler wire speeds

In Figure 9 an overview is given of the maximum strength levels that were obtained at different brazing speeds. The filler wire speeds at which these results were obtained are given in the same figure. At lower brazing speeds (1 and 2 m/min.), the specimens failed in the steel base material outside the joint area (Figure 10). At higher brazing speeds the joints themselves failed but still at very respectable strength levels. Brazing speeds higher than 4 m/min have simply not yet been attempted but may very well be possible, although a somewhat lower strength is to be expected. The brazing speed achieved with Fluxless Laser Brazing is at least comparable to the speed achievable with a flux based process. At Corus RD&T, the highest speed achieved up to now with a flux based laser brazing process has been 3 m/min.

The optimum filler wire speed depends on the brazing speed. The higher the brazing speed, the higher the required filler wire speed (Figure 9). At a brazing speed of 1 m/min. the optimum filler wire speed was found to be 6 m/min. whereas at a brazing speed of 4 m/min. an optimum filler wire speed of 12 m/min. was found. Even so, the higher amount of filler wire per unit of time does not completely compensate for the higher travelling speed, and as a consequence, the amount of filler wire per unit of joint length decreases with increasing brazing speed, from 6 meter of filler wire per meter of joint length at a brazing speed of 1 m/min., to 3 meter of filler wire per meter of joint length at a brazing speed of 4 m/min. The lower amount of filler material per unit of joint length at higher brazing speeds may explain the somewhat lower strength at these speeds. It is likely that this behaviour is governed by the power of the available laser source. With more laser power it may well have been possible to feed more filler wire into the process and achieve a higher strength at a brazing speed of 3 m/min. and 4 m/min. or to increase the brazing speed even further.

3.3 Material influence

Figure 11 gives an overview of the brazing results obtained on a range of material combinations. In one case the steel was electro galvanised (EG) in all other cases hot dip galvanised. With one positive exception, all material combinations gave very similar results; having a strength of around, or slightly above, 200 N/mm. Thus, one may conclude that both hot dip and electro galvanised steel can be joined with the Fluxless Laser Brazing process and the same can be said for the aluminium alloys AA6016 and
The high magnesium content in AA5182 (4.9%) did not have a negative influence on the results.

The only material combination that resulted in a completely different strength level was DP600 (1.1 mm) joined to AA6016 (2 mm), which was roughly twice as strong as all other material combinations. This is also the only material combination that both regarding the strength (DP600, being an advanced high strength steel) and the thickness (1.1 mm DP600 and 2.0 mm 6016) of the base materials deviates from the other combinations, which were all forming grade materials and in the same thickness range. Therefore it is likely that both the strength and thickness of the base materials have an impact on the joint strength that can be achieved with Fluxless Laser Brazing. It appears that the thicker and stronger the base materials, the higher the joint strength that can be achieved.

Figure 11 also contains the results of experiments carried out with two alternative filler wires. The AlSi3Mn filler wire is being promoted for use in combination with the CMT (Cold Metal Transfer) process, a MIG welding process with a relatively low heat input, and favourable results have been reported for this combination of filler wire and process [3]. A series of experiments was carried out to determine whether similar favourable results would be achieved with the Fluxless Laser Brazing process. Although certainly good results were obtained in our experiments, the results appear not to be better than obtained with an AlSi12 wire.

Also a comparison was made between 1.6 mm and 1.2 mm diameter AlSi12 filler wires (Figure 11). The strength obtained with the 1.6 mm filler wire was about 10 to 20% less than obtained with the 1.2 mm wire, which is thought to be caused by a geometrical effect. During the brazing process, the filler material fills the area between the steel and
aluminium and forms a, more or less, triangle shaped joint (Figure 4). A relative thin filler wire will be better capable of filling the 'root' of this triangle (the area towards the bottom in Figure 4) than a larger diameter wire. As a result, one may expect somewhat stronger joints when using a relative thin filler wire.

4 Summary and conclusions

A laser based process was developed, which was named Fluxless Laser Brazing, capable of joining aluminium to steel without requiring a flux. A range of material combinations was successfully joined in a T-configuration: hot dip and electro galvanised forming grade steels and hot dip galvanised DP600 on the one hand and AA6016 and AA5182, the latter containing 4.9% magnesium, on the other hand.

Often joint strength levels close to, and sometimes even above, the strength of the weaker of the two base materials were achieved.

The thickness of the intermetallic layer could be controlled to a level of 1 µm or below.

Favourable results were achieved up to a brazing speed of 4 m/min. A speed that is at least comparable to what can be achieved with a flux based laser brazing process.

One of the key advantages of this process when it comes to optimising the joint properties is the freedom to select laser power, brazing speed and filler wire speed completely independently from one another.

It appears that the available laser power is the key parameter that defines the limits of the process. It is likely that with more laser power higher brazing speeds and stronger joints at higher brazing speeds are possible.

All in all, Fluxless Laser Brazing appears to be a technology that is very well suited for joining aluminium to steel in automotive applications.

5 References

