

MECHANICAL EVALUATION OF JOINING METHODOLOGIES IN MULTI MATERIAL CAR BODY

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ABSTRACT

The economical use of energy and other limited resources and the protection of the environment will be one of the main influencing cornerstones of tomorrow's mobility. Intensive efforts in the automotive industry focus on further reduction of CO₂ emissions and higher energy efficiency in all phases of vehicle life cycles. Consequent development of lightweight design plays a major role for further fuel consumption reduction. Innovative and sustainable lightweight structural design can be developed only in an integrated approach through global consideration of intelligent design concepts and material technologies together with applicable manufacturing methods. Innovative approaches have to be assessed across the target conflict of weight reduction needs and economic justification to identify the most suitable solutions within respective requirements. Innovative hybrid materials and intelligent multi-material design show high application potentials for future car body light weight strategies.

KEYWORDS: Multi-Material, Car Body, Joining, Methodologies, Mechanical, Evaluation

I. INTRODUCTION

As the time progresses, there is a dire need for the reduction of CO₂ emissions as the standards are getting more strict than before. Lower fuel consumption is also the main goal of every manufacturer. There has been a lot of research on the engine and CO₂ emissions, much technological advancement like EFI (Electronic Fuel Injection) were brought up increase fuel consumption efficiency and lower emissions. There are now numerous attempts being made to modify the body in white structure so to achieve the same tasks. Lighter weight of a vehicle ends up giving us our desired result in this field. For that purpose we will try to illustrate the methods of the weight reduction using multi-materials in the car body.

Car bodies are typically made of steel or aluminum. They left a lower choice of flexibility in reduction of weight and design. In contrast to single-material car bodies, multi-material technology allows best material selection in every part of the car for superior product performance and reduced cost. By using multi-materials we can optimize the weight of the car, using the specific material for a specific purpose. This approach gives us lot of choices and also makes our design more efficient. The main driver to develop new automotive construction is to reduce emissions, which have a harmful effect on climate; as well as reduction in fuel consumption. As a result, we have to consider reduction of automotive weight and consequently at different approaches for lightweight manufacturing.

Steel construction has already a capability for weight reduction in future but using multi-material design, this capability can be extremely improved. Nowadays research activities are mainly focused

on multi-material concept, with the target of introducing the material with the best properties for the given requirements in the right position. Based on various methods of lightweight construction, techniques and tools, it is possible to find an optimum between lightweight design and costs. These activities will be illustrated by several research examples.

II. MATERIALS

Before giving different solutions and approaches, let us look up into certain properties of different materials which are being implied in car design in place of steel alone. There are mainly two materials namely; aluminum and magnesium.

2.1 Aluminum

The European automotive industry has more than doubled the average amount of Aluminum used in passenger cars during the last decade and will do even more so in the coming years. We use the following types of Aluminum in our car body:

- i. Aluminum sheet
- ii. Aluminum die cast
- iii. Aluminum extrusion

One of the main advances of aluminum is its availability in a large variety of semi-finished forms, such as shape castings, extrusions and sheet. Such semis are very suitable for mass production and innovative solutions in the form of compact and highly integrated.

Aluminum can be up to two-and-a-half times stronger than steel and can absorb twice as much crash energy. Vehicles made lighter with aluminum can have improved acceleration, braking, handling and better fuel economy. Finally, aluminum is easily repaired but it takes special techniques.

2.2 Magnesium

Pure magnesium is about one-third lighter than aluminum, and two-third lighter than steel. Lighter weight translates into greater fuel efficiency, making magnesium alloy parts very attractive to the auto industry. And these lighter parts come with good ductility and elongation properties, giving the materials good dent and impact resistance, as well as fatigue resistance. The alloys also display good high-speed machinability and good thermal and electrical conductivity.

Although magnesium alloys can be easily machined into various parts, they really stand out when die cast. They can be formed into complex shapes in one casting, often reducing cost by eliminating several steel stampings and the associated assembly.

The magnesium we used in our multi material car body is

- i. Magnesium sheet.
- ii. Magnesium Die cast

If you were to look at a cross section of a die-cast part, you would see a very thin skin (that's coatable, by the way) covering a fine interior microstructure. Once decried as magnesium's greatest weakness, this microstructure is now recognized as one of magnesium alloy's greatest strengths. It allows the material to be cast with very thin walls, optimizing design and decreasing the component's weight. The microstructure also gives the alloys good sound and vibration dampening qualities. In fact, many luxury cars use magnesium alloys for valve covers and other under-the-hood parts, keeping the ride nice and quiet.

Engineers like die casting with magnesium alloys because they can design to specific yield strength, fatigue, and creep criteria. There is a note of caution here, however. There is relatively no creep in magnesium alloys at room temperature, but if higher temperatures are anticipated in the application, the design will need to accommodate the resulting creep factors.

III. MATERIAL SELECTION METHODOLOGY

The choice of suitable materials can be very difficult for an engineer. For this purpose, the requirements for every part have to be identified and rated. The criteria are:

- i. Energy absorption
- ii. Structural integrity

- iii. Stiffness
- iv. Formability
- v. Surface quality

Same criteria are used to rate the material properties. A comparison of these criteria gives engineer an idea about the selection of possible materials. The next step is to involve additional criteria like:

- i. Cost
- ii. Life cycle analysis
- iii. Simulation
- iv. Corrosion
- v. Joining
- vi. Producibility

3.1 Simulation

After choice of materials, Design of the proposal is checked by simulation.

IV. JOINING TECHNOLOGIES

One of the most important and difficult steps in giving the real life shape to the multi material car body is the selection and definition of a suitable joining method between two different materials.

Various joining techniques can be used by multi material concept in car designing due to diverse joining and geometrical configurations. Such techniques are highlighted as follows.

4.1 The Self-Tapping Screws

Already used in models such as the TT are also suitable for joining aluminum and CFRP parts, such as in the area of the longitudinal member.

4.2 Friction Stud Welding

Another high-end method, friction stud welding, is used to join steel and aluminum.

4.3 Rivet

A steel element, a kind of rivet, penetrates an aluminum panel while rotating at high speed and under great pressure, creating a friction-welded joint with the steel sheet below.

4.4 Resistance Spot Welding

RSW is most commonly used technique for hot pressed steel due to low cost and robustness in process. There are also many promising developments in rivet technology and in aluminum resistance spot welding.

4.5 Roller-Type Hemming

Another innovative joining technique is roller-type hemming. Here rollers secured to a robot arm bend the outer panel over the inner panel and create a powerful connection by the application of a hem-bonding adhesive. The add-on components on the new A8 (doors, bonnet and tailgate) and the connection of the wheel arch with the side-panel frame are processed in this way.

4.6 Inductive Gelling

In this process, the hem-bonding zones on the add-on components are heated through targeted induction (electric field) that hardens the hem-bonding adhesive. The component is thus stabilized and any slipping of the outer panel to the inner panel is avoided.

4.7 Laser Beam-MIG-Hybrid Welding

This is brought about among other things by innovative manufacturing processes. There is thus a combination, for example, of the conventional laser and arc welding process in the laser beam-MIG-hybrid welding process (MIG stands for Metal Inert Gas) which is completely new in vehicle construction with aluminum.

4.8 Adhesive Gluing

Continuous joining is important due to static and dynamic requirement of light structure i.e. lower modulus material structure.

It eliminates the risk of corrosion posed by the carbon-reinforced materials while simultaneously sealing the joint.

4.9 Friction Stir Spot Welding

This technique is mainly used for spot joining aluminum instead of riveting. Care must be taken to the tool life duration in order to keep the cost under allocated budget.

4.10 Semi Hot Welding

This technique is very promising when used for edge or angle joining with single sided access possibilities. It includes MIG, cold metal transfer (CMT) and laser weld brazing techniques. Semi hot welding enables to use hollow sections in space frame thus reducing overall weight of the car body.

4.11 Cold Joining (Self Piercing Riveting)

It is widely used technique for keeping same geometrical configuration and assembly placement. Self piercing riveting is an important solution for joining the non-weld able materials like magnesium plus aluminum and magnesium plus steel sheet.

Table1. Processes vs. Material Combination

Material Combination	Resistance Spot welding	Laser and Arc welding	Self Piercing Riveting	Friction Steel welding
Steel to Steel	√	√		
Steel to Al	√	√		
Steel to Mg			√	√
Al to Al				
Al to Mg			√	√
Mg to Mg			√	
CFRP to Steel			√	
CFRP to Al			√	

V. MATERIAL COMBINATION

5.1 Steel to Steel Joining

The material choice strategy for the future is to not only to decrease weight or make the car safer but is also anything that will help build a successful vehicle. If the material is successful in meeting very particular performance goals - noise, vibration, airflow, weight and, of course, cost then it will be used.

5.1.1 Resistance Spot Welding

Resistance Spot Welding is widely adopted steel to steel joining technique due to low cost, easy automatization and robustness. The time cycle for current assembly lay out time is 3 sec. The involved robot produces 20 spots per minute time cycle. First characteristic is spot weld shearing strength increases with assembling thickness from 1 mm to 4 mm currently used in car bodies. By keeping the spot diameter greater than 5 times of the assembly thickness, much better results can be obtained. Note: for better quality in results keep Spot diameter ≥ 5 times Assembly thickness. Another characteristic with respect to shearing strength and pulling strength is that one will decrease and the other will increase accordingly. The ratio between their shear strength and pulling strength decreases from 0.5 to 0.3. This impact is because of reduction in ductility caused by steel increasing harden-ability. However; the results are not much affected because the unibody structure is mainly subjected to shearing stresses instead of pulling stresses.

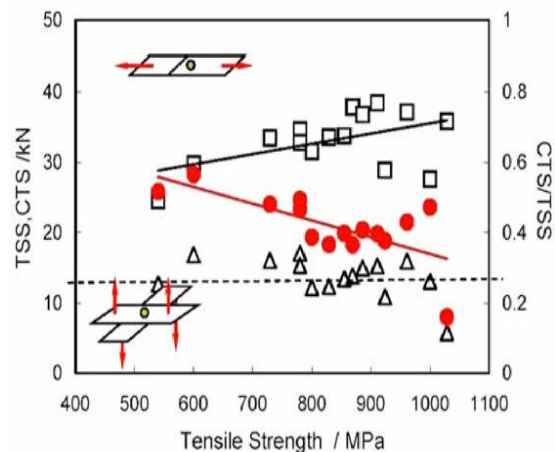


Fig. 1 Tensile Shear Stress vs. Steel Strength

Arcelor improves Resistance Spot Welding in hot pressed steel is improved by Arcelor. This improvement is caused by increasing induced energy for producing high strength spot welds increasing with assembly sheet thicknesses and by enlarging welded nugget diameter.

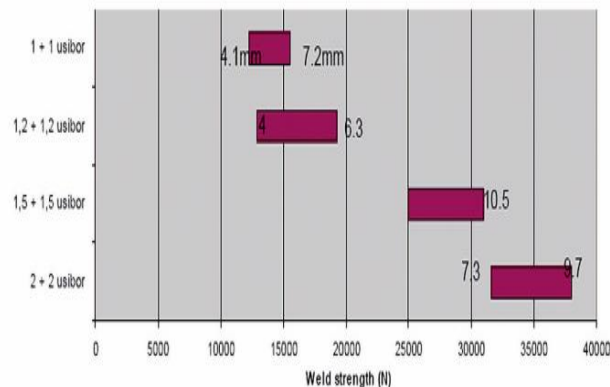


Fig. 2 Spot Welding Strength vs. Arcelor

Third characteristic of resistance spot weld strength is superior to self piercing riveting and clinching when assembly thickness increases as shown in Fig 3.

	Steel grade	LSS DC04	Dispersoid S355MC	TRIP Fe-Mn	TWIP Fe-Mn	
	UTS	E 280	E 360	E 450	E 830	All Steels
	YS	R 360	R 480	R 600	R 1000	
Assembly thickness (mm)	Spot diameter (mm)	Shearing load (kN)	Shearing Load (kN)	Shearing Load (kN)	Shearing Load (kN)	Pulling Load (kN)
0,6	3,3	1,9	2,3	3,1	4,1	1,8
1,0	4,3	4,2	4,9	6,7	8,7	4,0
2,0	6,0	11,8	13,8	18,9	24,6	11,3
3,0	7,4	21,7	25,5	34,7	45,1	20,8
4,0	8,5	33,4	39,2	53,5	69,5	32,0

Fig. 3 RSW Characteristic vs. Assembly Thickness

The resistance spot welding gives better results with respect to strength as compared to clinching and self piercing riveting.

5.1.2 Laser and Arc Welding

The resistance spot welding is restricted by joining speed average to be 1 m/min .This speed can only be increased by Laser Welding typically until equivalent speed of 5 m/min or 0.5 s per equivalent weld spot.

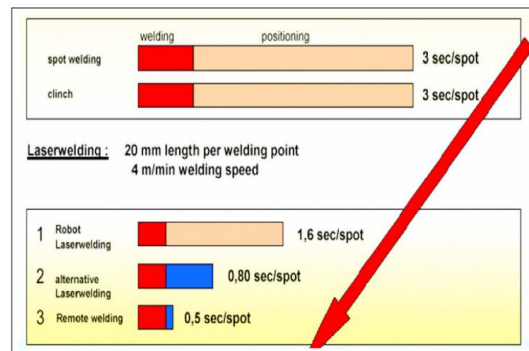


Fig. 4 Assembly Productivity vs. Laser Welding Systems

Laser welding was primarily applied for continuous overlap joining using CO₂ then yttrium aluminum garnet (YAG) lasers. Nowadays many car manufacturers use it for roof -body side joining. This usage was not widely appreciated until T angle joining configuration made it efficient for suppression in roof molding.

To get better integration high cadence time cycle one should use 3 kW power laser T weld brazed joining speed is > 2.5 m/min. New lasers sources using SLAB CO₂, disk or fiber improve beam quality. This improvement enables longer focusing to perform "Laser Remote Welding" and also separation of laser head and clamping tools. This adoption is efficient for assembling "flat" parts with main advantage of improvement in passenger visibility by smaller flanges width.

The induced brittleness at grain boundaries is caused by Arc welding aluminum. Resultantly leaving aluminum coating weld brazing is more suited for lap edge joining. Cold metal transfer or pulsed MIG was successfully used with Cupro silicon filler wire for lap edge joining hot pressed parts with high join strength ≥ 30 daN/mm.

In bending and torsion, both material and shape are important parameters for the efficiency of the component to carry the applied load [5].

5.2 Aluminum to Steel Joining

Main solution to save weight is progressive introduction of Aluminum consequently aluminum steel joining is a key issue. Most current solution is cold joining often adhesive gluing with riveting needed for clamping parts before glue curing. Hybrid joining is more costly consequently new simpler processes have been worked out. Aluminum steel is not weld-able by process techniques inducing

liquid phase because of formation of brittle inter-metallics. Monitored Resistance Spot Welding proceeds by solid state diffusion of aluminum steel have been developed in Japan by Kobelco.

5.2.1 Resistance Spot Welding

Resistance spot welding of aluminum-steel uses current control versus impedance to promote just needed fusion for limiting intermetallic. This enables to increase the spot "welded" diameter and spot shearing strength versus welding current.

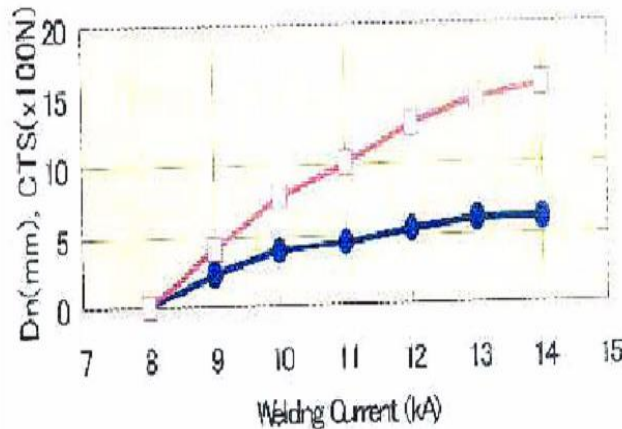


Fig. 5 Spot "Welded" Diameter and Spot Shearing Strength vs. Welding Current

Friction Stir Spot Welding is another solid state process looks very similar to apply as Resistance Spot Welding. Process parameters are easy to manage as a machine tool.

Welding guns produced by Kawasaki are similar to resistance spot welding. Spot weld strength is produced by penetration of tool pin in assembling. Work carried out by Phd Bozzi demonstrates that spot strength is promoted by dimensions of steel hanging zone in aluminum. Typical produced spot strength = 350 daN for 2 mm assembly thickness; is equivalent to self piercing riveting.

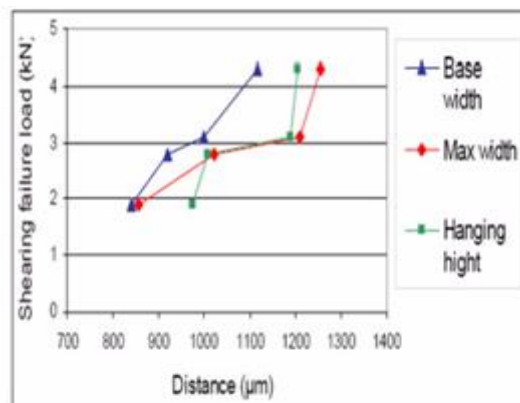


Fig. 6 Spot Weld Strength vs. Distance of Weld

Industrialization benefit depends on tool durability which has been recently improved from 450 spots by using W-Re 25% alloy to 2000 spots by using coated CW material from Boehlert.

5.2.2 Arc, Arc Laser (Lap Edge Joining)

Fusion welding process produces inter-metallic at Al-steel interface. Thickness increases with overheating and may decrease with cooling rate. Thickness should be less than 20 μm to avoid brittleness. AC and DC MIG processes produces satisfactory weld brazed lap edge joints with control of inter-metallic thickness. Central Electricity Authority (CEA) developed MIG flat wire process with possibility to enlarge gap tolerances until 2 mm. Tensile shear strength of overlap specimen meet

basic aluminum strength by production of a thick diffusion layer = $40\ \mu$ quasi without intermetallic = $1.5\ \mu$. Tooling coil progress is still needed to acquire robustness.

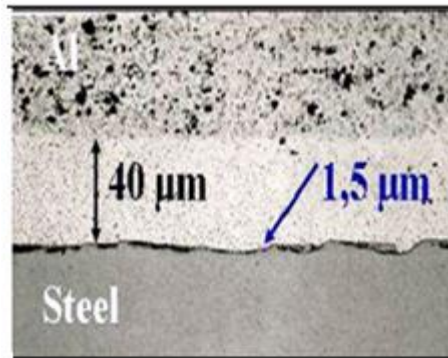


Fig. 7 Diffusion Layer

To summarize arc and hybrid arc weld brazing joint strength decreases when welding speed increases. Geometrical criteria for high lap edge joint strength includes large interface length > 3 upper sheet thickness for all arc weld brazing processes. Work results can be summarized by weld brazing strength-speed diagram: arc MIG and hybrid arc laser weld brazing joint strength decreases when welding speed increases.

5.2.3 Self-Piercing Riveting

Clinching and self-piercing riveting for joining magnesium alloy die-castings to steel and aluminum alloy sheet. Ordinarily, these processes cannot be used for joining magnesium die-castings due to their low ductility. The clinching process for joining magnesium die-castings to steel and aluminum sheet has been used very successfully. Self-piercing riveting also offers the ability to set a threaded or shaped head into magnesium. So, attachments for fixing trim in place or for screw fittings can also be attached to magnesium die-castings.

5.2.4 Frictions Stir Welding

Magnesium alloy components present joining difficulties when integrating the die-castings into the rest of the structure, particularly where joints between magnesium and aluminum or steel are required. The only method currently available for completing such joints is bolting, but this adds weight and cost, requires accurate alignment and can create problems of fretting and wear between the bolt and the softer magnesium alloy.

Alternative methods of joining magnesium to dissimilar metals are essential if the cost of using lightweight magnesium components is to be reduced and weight savings maximized. Seam welds are possible using friction stir welding.

VI. EFFECT OF COST

To summarize multi-joining processes data a technical economic synthesis may be tried. Steel-steel joining is less costly. Aluminum-steel joining is possible by several processes depending on priority: joint strength versus joint speed should be a compromise. Effort is still needed to improve joining multi-materials performances for reducing weight saving over cost.

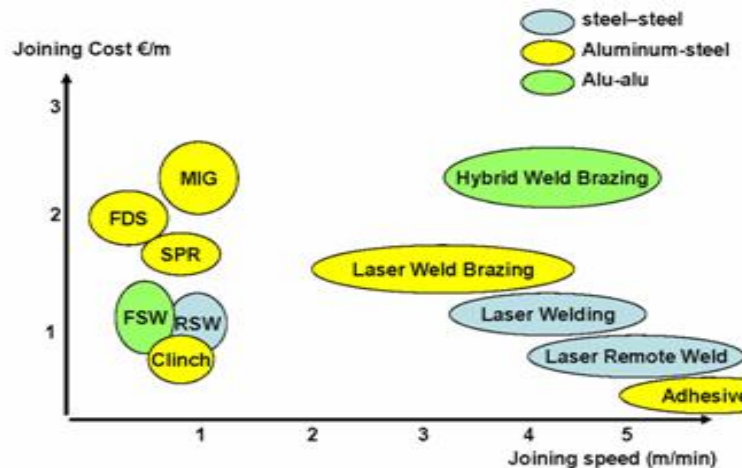


Fig. 8 Comparison of joining cost & speed for multi materials joining

VII. CONCLUSION

The multi-material concept has established to be very capable in terms of weight reduction and cost feasibility. Based on this, it is the manufacturer who has to decide in the end which approach is most effective for him. It was revealed that different approaches for different lightweight ratios (cost per reduced weight) are possible. The paper also showed that extensive work is still needed on developing joining techniques for parts made of multi-materials. In this context, adhesive bonding has demonstrated its high prospects, but still has to achieve dynamic simulation capabilities. Perfect Joining methodologies are the target for the future, always taking the issue of cost-reduction into account.

In order to reduce CO₂ emission, weight reduction must be considered. Weight reduction has close connection with technical development. In order to reduce weight, 3 issues need to be considered.

- i. Structure
- ii. Material
- iii. Process

In order to reduce the car weight, there is trade off amongst communization strategy, performance, cost, etc. Balancing of those factors is required. For further weight reduction, it is necessary to consider the car in “total” not in just by one part/unit. Car structure will shift to “Multi-Material” thus optimization to apply best material and process will be essential.

The Light weight car is one of the needs of the present and especially future automotive industry while multi material car body is one of the main solutions. In multi material car body one of the challenging and most important part is the joining techniques between these materials. The swap among different techniques depends solely on materials to be joined (e.g. Al, Mg, steel, plastics), thickness of the work piece in hand, stress value, proper orientation, geometrical assembly configuration (e.g. angle, edge, overlap etc) and most importantly on joining speed effecting cycle time.

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