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Review

Joining of automotive sheet materials by friction-based welding methods: A review

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ABSTRACT

The demands for higher fuel efficiency in the automotive sector have motivated the increased use of multi-material combinations for lightweight designs in recent years. This has inevitably led to challenges in joining materials where aluminum alloys, magnesium alloys, and steels (*i.e.* low, medium and ultra-high strength) are combined. Since each of these materials offer varying performance and property advantages for various components, they have been introduced progressively in different locations of new designs. Consequently, these material combinations will inevitably need to be joined, which presents major challenges due to their incompatibility during conventional fusion welding processes used in vehicle manufacture. This paper summarizes recent progress in friction-based techniques for joining dissimilar material combinations, and discusses factors controlling bonding and joint strength. Since friction stirs welding (FSW) and its sub-family do not involve bulk melting of the components (the peak temperature in FSW is about 0.6–0.95 melting point of materials), it is among most capable welding techniques for joining dissimilar materials. In the automotive industries, the attention and application of FSW has been in three general sets. These include the joining of extruded parts to form “larger extrusions”, the joining of tailor welded blanks, and the joining for various assembly applications. FSW in each of these has diverse advantages and resulting cost reductions. However, cost effective and reliable joints of light weight alloys (*i.e.* aluminum) and steel will demand significant development and consideration. The purpose of the present review paper is to assess the status of friction-based solid state welding of dissimilar automotive alloys, with specific attention to the automotive industry, future trend, challenges and limitations. The main difference between the FSW of similar and dissimilar alloys is the incoherency in properties across the butting surfaces which has a significant influence on the flow behavior of materials during stirring.

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1. Introduction

The need for improved fuel economy and reduced emissions has been emphasized by the US government and Corporate Average Fuel Economy (CAFÉ) program mandating higher fleet efficiency each year. The International Council on Clean Transportation has also shown that aggressive targets of 95 g CO_2/km for vehicle emissions can be met by light-weighting [1,2]. This has driven a number of technological developments in terms of materials performance, such as high strength aluminum and magnesium alloys with increased formability, lower cost carbon fiber composites, and hot stamped ultra-high strength martensitic steels which have much higher strength to weight ratios than conventional steels. Given that each of these materials have specific advantages and disadvantages in various locations or applications within a vehicle design, it is possible that these materials are used simultaneously in different locations to optimize mechanical performance for each application. Although many auxiliary issues with these materials are being progressively addressed (such as corrosion, formability, and production cost), an ongoing challenge remains the weldability of dissimilar material joints. Fig. 1, for example, shows the frame of the 2014 Alfa Romeo 4C design, in which ultra-high strength steel bumpers are used for crash resistance, an aluminum frame is used for suspension components and a carbon fiber composite tub make up the main internal structure in order to keep the final vehicle mass below 900 kg. In this case, fasteners were mainly utilized for dissimilar joining, however higher production volumes and lower costs often demand that welding be employed.

The use of friction stir welding (FSW) offers potential for dissimilar joining components where costs prohibit the use of fasteners, adhesives, or self-piercing rivets. The main challenge stems from the different properties (*i.e.* physical and mechanical), composition, and structure (*i.e.* crystalline) which lead to detrimental weld properties. Since FSW does not involve bulk melting of the components (the peak temperature in FSW is about 0.6–0.9 of the melting point of materials in degrees Kelvin) [1], it is among most convenient welding techniques for joining dissimilar materials. Given the many advantages including improved mechanical properties (tensile and fatigue), improved process robustness, lack of consumables, reduced health and environmental issues, and lower operating costs, FSW has gained significant interest in the automotive industries and manufactures [3]. In the automotive industries, the attention and application of FSW has been in three general areas. These include the joining of extruded parts to form "larger extrusions", the joining of tailor welded blanks, and spot joining for various assembly applications. FSW offers numerous advantages and potential for cost reductions in each of these cases. However, cost-effective and reliable joints between light-weight materials will demand significant development and further consideration.

It worth mentioning that while FSW is a solid-state technique, using it to join dissimilar material with desperate melting points will always result in some melting [4–7]. The present paper summarizes some of the recent advances that have been made in using FSW for dissimilar welding, in both spot joining and seam welding applications. The main advantage common to nearly all the techniques is that solid state processing limits the temperature rise within the weld region. This prevents the formation or growth of undesirable and brittle intermetallic compounds within the weld which deteriorate strength. Lower peak temperatures also minimize thermal distortion and residual stresses, which can often lead to the fracture of the joint immediately upon cooling of the weld in

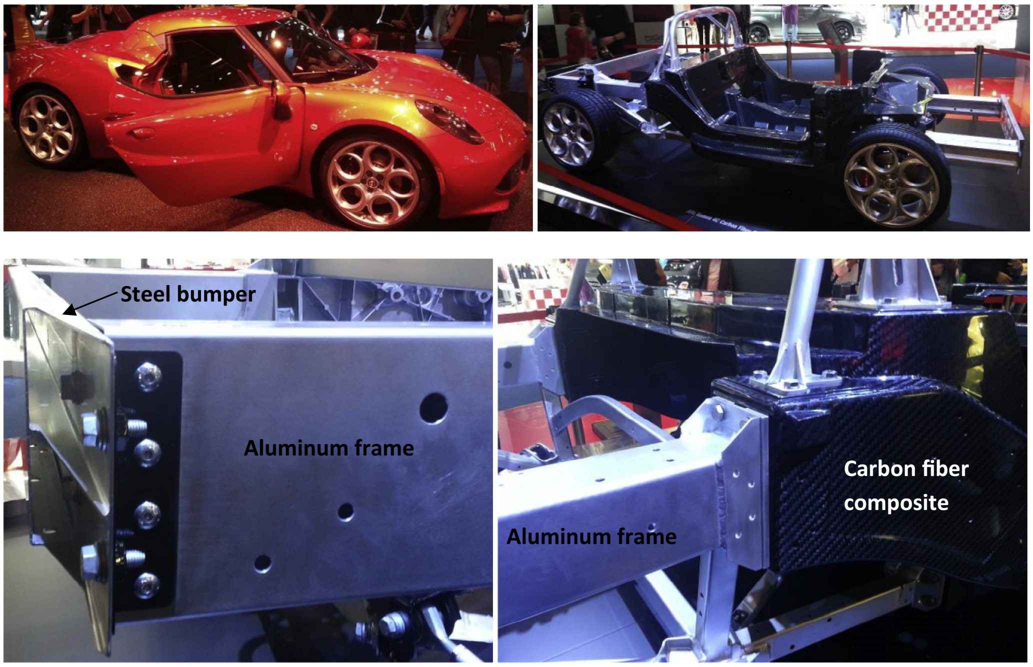

Fig. 1. Example of multi-material design used in the 2014 Alfa Romeo 4C, where fasteners are used to join high strength steel, aluminum alloy, and carbon fiber composite.

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