Challenges in Welding Lightweight Materials

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Why Use Lightweight Materials?

Elevated greenhouse gas emissions have led to significant ecological changes, including a global rise in temperature. Increasing atmospheric CO$_2$ concentration from energy production, manufacturing, and automotive emissions is a primary concern. Global CO$_2$ emissions have reached 24 billion tons per year, and approximately 25% of these emissions are produced by automobiles. To address this, significant efforts have been made to improve automobile drivetrain efficiency; however, additional improvements in overall automobile design are necessary. The most recent approach is to reduce vehicle weight, allowing smaller engines to be used, thereby reducing fuel consumption. A weight reduction of 220 pounds can reduce fuel consumption by one gallon over a distance of 600 miles and can reduce CO$_2$ emissions by about 5 grams per mile, representing a reduction of approximately 5%.

Figure 1: Cars account for 25% of global CO$_2$ emissions

Reducing Weight

Generally, there are three ways to reduce vehicle weight: material substitution, vehicle redesign, and vehicle downsizing. Material substitution involves replacing steel alloys with lightweight materials, such as aluminum, magnesium, advanced high-strength steel (AHSS), metal composites, and plastic/polymer composites. These substitutions can be used to decrease auto-body and chassis weight, therefore leading to lighter engines, batteries, fuel tanks, and fuel loads. To enable their use, lightweight materials must be designed and developed to meet performance requirements in different areas of automobile construction.

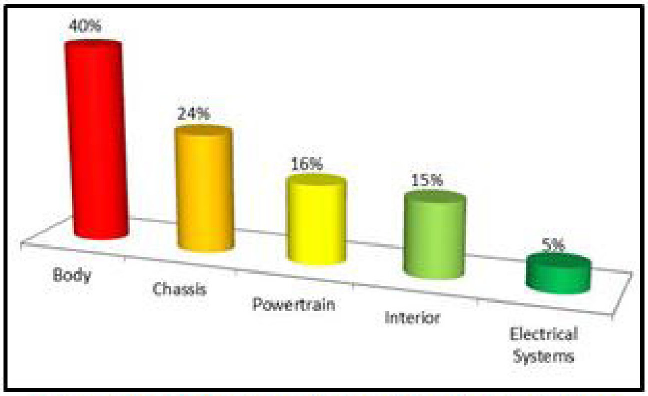

Figure 2: Vehicle mass distribution by subsystem

Aluminum and AHSS alloys are the main candidate materials to replace carbon steel. Lighter-weight and higher-strength options include magnesium and polymer composites, as well as carbon-fiber-reinforced thermosets and thermoplastics. Metal matrix composites and titanium are less commonly used due to their high costs. Manufacturers are interested in using a mixture of lightweight materials to ensure adequate strength to sustain crash impact forces, facilitate manufacturability using their existing infrastructure, and maintain or improve life-cycle performance at a reduced cost. This mixed-material strategy significantly impacts assembly and joining methods, and appropriate construction principles and joining technologies must be considered.

Welding Challenges

Different materials and material combinations pose unique welding challenges that must be addressed.

High Strength Steel Alloys Challenges in welding high-strength steel (HSS) alloys include base metal alloying elements (Nb, Ti, V, etc.) that promote precipitation and carbide formation, grain growth in the coarse-grained heat affected zone (CGHAZ), softening in the heat affected zone (HAZ), and susceptibility to hydrogen assisted cracking (HAC). In addition, methods of calculating carbon equivalent and predicting preheat temperature are of limited validity.

Advanced High Strength Steel Alloys Higher carbon and alloying element contents make AHSS alloys more sensitive to the thermal cycles experienced during welding, resulting in greater variations in microstructures and resultant weld properties. Both the chemistry of the specific AHSS alloy and the welding conditions used to join it can significantly affect the microstructure, so welding practices developed for one type of AHSS may not apply to others. In addition, HAZ softening is more pronounced in higher grade steels. Additional challenges include the prediction of the static, fatigue, and impact/crash performance of these welds, and the fact that the wide range of grades and types of AHSS alloys continues to evolve.

Aluminum Alloys While aluminum alloys are susceptible to hot cracking, oxide inclusions, dross, and porosity, the specific chemical composition of each alloy determines its weldability. Most wrought series aluminum alloys including 1xxx, 3xxx, 5xxx, 6xxx, and medium strength 7xxx series can be joined using gas tungsten arc welding (GTAW) or gas metal arc welding (GMAW), while 2xxx and high strength 7xxx are not readily weldable using these processes due to liquation and solidification cracking issues. As shown in figure 3, alloy level determines the types of discontinuities that can be expected.

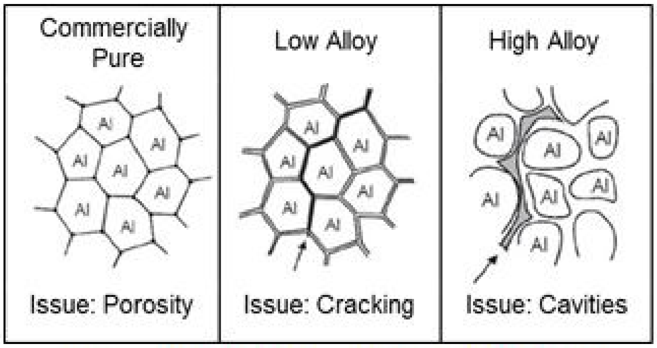

Figure 3: Effect of alloy content on weld quality

Magnesium Alloys Much like aluminum, magnesium has a low melting point, high thermal conductivity, high thermal expansion, and a tenacious oxide surface coating. Recrystallization and grain growth in the HAZ of work-hardened magnesium lowers overall joint strength. In Mg-Al-Zn alloys (AZxx), Al content higher than 10% improves weldability by refining grain structure, while Zn content higher than 1% increases hot shortness.

Welding Dissimilar Metals and Alloys When welding dissimilar metals and alloys, a transition zone exists where intermetallic compounds are commonly formed. If the two materials have mutual solubility, the dissimilar joints can be made successfully. If there is little or no solubility, a successful joint cannot be made using arc welding processes. Intermetallic compounds are detrimental in that they increase crack sensitivity, reduce ductility, and increase corrosion susceptibility.

Differences in the coefficient of thermal expansion may lead to high residual stresses in the inter-critical HAZ, leading to service failure. Variations in melting temperatures are also problematic, since one metal may be overheated before the other when both are subjected to the same heat source. Additionally, a significant difference in electrochemical potential can increase the susceptibility to corrosion in the HAZ, posing a serious problem.

How EWI Can Help

EWI has significant expertise in the characterization of similar and dissimilar weld joints. With extensive in-house capabilities, we can perform accurate weldability assessments using simulation, analytical, and experimental methods, combined with an in-depth understanding of material property requirements (Figure 4). EWI has developed and performed testing on a wide array of lightweight materials, including HSS, AHSS, Al alloys, Ti alloys, Mg alloys, and composite-reinforced materials.

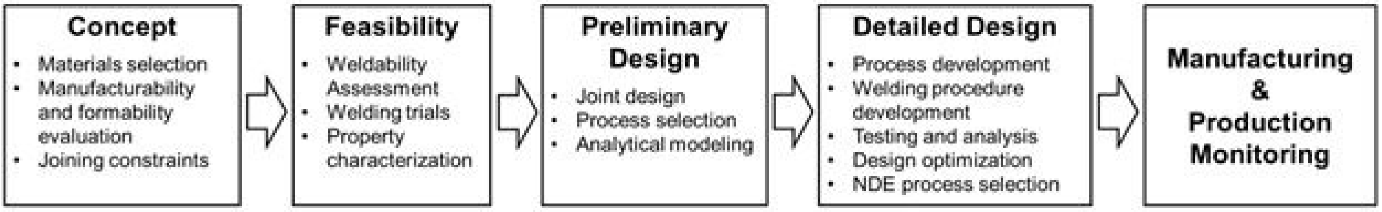

Figure 4: EWI's weldability problem solving approach

Our full suite of software and testing facilities allows us to predict and improve weld joint performance through structural modeling, select proper welding techniques, recommend improved welding electrodes, and perform microstructural analysis and characterization. Our experts can also help manufacturers select non-destructive testing methods to ensure joint quality and performance.

***Alber Sadek** is an applications engineer in EWI's Materials group where he investigates the effects welding parameters, welding processes, and shielding gas composition have on the microstructure and mechanical properties of different alloy weldments. His current work involves the selection of metals and alloys as they are applied in different industrial sectors, covering their physical properties, material characterization, weldability (similar/dissimilar alloys), corrosion, wear, fatigue, and creep properties.*