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Investigations on laser beam welding of different dissimilar joints of steel and aluminum alloys for automotive lightweight construction

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Abstract

Due to the enormous potential of weight saving, and the consequential reduction of pollutant emissions, the use of hybrid components made of steel and aluminum alloys is increasing steadily, especially concerning automotive lightweight construction. However, thermal joining of steel and aluminum is still being researched, due to a limited solubility of the binary system of iron and aluminum causing the formation of hard and brittle intermetallic phases, which decrease the strength and the formability of the dissimilar seam.

The presented results show the investigation of laser beam welding for joining different dissimilar hybrid components of the steel materials HX220LAD+Z100, 22MnB5+AS150 and 1.4301, as well as the aluminum alloy AA6016-T4 as a lap joint. Among other things, the influences of the energy per unit length, the material grade, the sheet thickness *t*, the weld type (lap weld, fillet weld) and the arrangement of the base materials in a lap joint (aluminum-sided irradiation, steel-sided irradiation) on the achievable strengths are analyzed. The characterization of the dissimilar joints includes tensile shear tests and metallographic analyses, depending on the energy per unit length.

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Keywords: dissimilar joints; steel-aluminum; intermetallic phases; laser beam welding; automotive lightweight construction

1. Introduction and Motivation

In 1993 the Council of the European Union (1993) has adopted a resolution for a decrease of the pollutant emissions of 20 % compared with the emissions of 1990 until the year 2020. Because the traffic causes 26 % of the

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total emissions of carbon dioxide (CO_2) in the European Union (EU) and the automobile traffic represents 46 % of them, the average CO_2 emission of new vehicles should be reduced to 95 g/km until the year 2020.

Due to the direct relation between the fuel consumption and the amount of CO_2 emission, the automotive industry has been focused on the development of different approaches for decreasing the fuel consumption. In addition to a decrease of the driving resistance and an increase of the energy efficiency of the engines, the weight reduction of the vehicles and accordingly lightweight construction are of particular importance. As a result of steadily increasing requirements for comfort and driving dynamics, the approaches for lightweight construction are mostly applied in the frame and body construction.

Hybrid constructions of steel and aluminum alloys cause a demand for loadable dissimilar joints and appropriated joining technologies, respectively. Therefore, several joining methods for hybrid components of steel and aluminum alloys are available. Due to an increasing importance of industrial automation and accessibility for frame and body constructions with steadily increasing complexities, the laser beam welding is an appropriate joining technology for these applications. Because the laser beam welding is a thermal joining method, this technology entails metallurgical challenges besides its advantages. Thermal joining methods for dissimilar joints of steel and aluminum alloys cause the formation of hard and brittle intermetallic phases, due to a limited solubility of the binary system of iron and aluminum, which decrease the strength and the formability of the dissimilar seam. Diffusion processes are already affecting the mixing ratios of aluminum to iron of solid-state materials, whereby these effects are much higher for liquid-state materials. As a consequence of the negative influences of the intermetallic phases on the strength and the formability of dissimilar seams, their formation should prevented as far as possible.

Nomenclature

b	weld width
CO_2	carbon dioxide
EU	European Union
GMAW	gas metal arc welding
λ	wavelength
P_L	laser beam power
t	sheet thickness
t_E	penetration depth
$t_{E, Al}$	penetration depth in aluminum alloy
v	welding speed
z	focal position

2. State of the Art

Before the development of efficient thermal joining methods, the manufacturing technology in the automotive industry for the joining of dissimilar materials was dominated by mechanical joining methods, e. g. rivetting (blind riveting and punch rivetting), clinching and screwing, as mentioned by Horst (2013) and Büdgam et al. (2004). Some mechanical joining methods as rivetting or screwing require additional components and entail partially a both-sided accessibility to the joining zone.

Furthermore, adhesive bonding methods are favourable joining technologies for dissimilar materials, among other things due to the relatively low process temperatures. The adhesive utilized are based on different polymers in dependence on the application and consists often of epoxy resin or methacrylate, as mentioned by Horst (2013), or of caoutchouc or polyurethanes for the automotive industry, as mentioned by Thomas et al. (2004). An essential disadvantage of adhesive bonding is the requirement for a fixing of the joint partner during the hardening process of the adhesive, as mentioned by Jost et al. (2007). In addition, the adhesive bonding methods are often combined with other joining methods, e. g. resistance spot welding, as mentioned by Arndt et al. (2013), blind riveting, punch riveting or screwing, as mentioned by Thomas et al. (2004), and are termed as hybrid joining.

As a solid-state welding process, the friction stir welding is also a favourable joining technology for dissimilar