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# High-power laser welding of thick steel-aluminum dissimilar joints

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**Abstract**

According to the Intergovernmental Panel on Climate Change (IPCC), a worldwide reduction of $CO_2$-emissions is indispensable to avoid global warming. Besides the automotive sector, lightweight construction is also of high interest for the maritime industry in order to minimize $CO_2$-emissions. Using aluminum, the weight of ships can be reduced, ensuring lower fuel consumption. Therefore, hybrid joints of steel and aluminum are of great interest to the maritime industry.
In order to provide an efficient lap joining process, high-power laser welding of thick steel plates (S355, t = 5 mm) and aluminum plates (EN AW-6082, t = 8 mm) is investigated. As the weld seam quality greatly depends on the amount of intermetallic phases within the joint, optimized process parameters and control are crucial. Using high-power laser welding, a tensile strength of 10 kN was achieved. Based on metallographic analysis, hardness tests, and tensile tests the potential of this joining method is presented.

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## 1. Motivation

For lightweight construction, steel-aluminum hybrid material combinations are of high interest, due to their properties regarding strength (steel) and density (aluminum). Such hybrid material combination can be used to minimize the weight of parts. Many steel-aluminum applications are already used in the manufacturing of car bodies (Brüdgam et al., 2004; Bayraktar et al. 2008; Assunção et al., 2010). Besides the automotive sector, lightweight construction is also of high interest for maritime industry to reduce the weight of ships and subsequently the $CO_2$-emissions. The consumption of fuel must be limited in order to fulfil requirements concerning $CO_2$-emissions (Waterborne Strategic Research Agenda, 2011; El Moctar, 2010). The Intergovernmental Panel on Climate Change

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(IPCC) led in the Energy Efficiency Design Index (EEDI) for the global freight traffic. This regulation stipulates that new ships have to be 30% more efficient by 2025. The aim is a reduction of $CO_2$-emissions of up to 263 million tons (The International Council on Clean Transportation, 2011). Lightweight construction is also of high interest for yachts and military ships to lower the center of gravity of the ship and thus stabilize it enabling an increase of speed (Schiffbautechnische Gesellschaft, 2001). Thus, the yacht design employs ship hull of steel and deck constructions of aluminum alloys. To join both parts, an explosive welding adapter is applied, but the manufacturing of this adapter is complex, time-consuming and costly. These adapters have a oversized thickness, depending on the material thickness of the steel and aluminum alloys, in order to meet the required strength. Fig. 1 illustrates an explosive welded adapter (left) (Buijs, 2004) and an example of a steel-aluminum application in the ship sector (right) (FSW-Ship project, 2013).

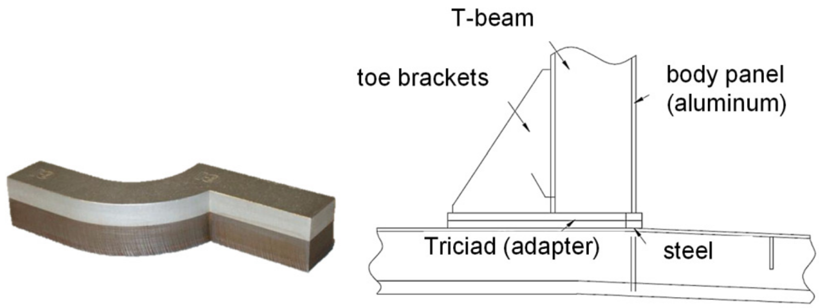


Fig. 1. Explosive welded adapter (left) (Buijs2004) and a typical application of steel-aluminum components in the ship sector (right) (FSW-Ship project, 2013).

The aim of the presented investigation is to develop a laser welding process in keyhole-modus for joining steel (S355, t = 5 mm) to aluminum (EN AW-6082, t = 8 mm) plates and to characterize the weld seam.

## 2. State of the art

### *2.1. Mechanical und chemical properties of formed intermetallic compounds*

Thermal joining of steel and aluminum is associated with high challenges regarding material and process, due to the different physical properties of iron and aluminum (Klock et al., 1977). Especially, the different melting temperatures, thermal conductivity and thermal expansion lead to induced tension and distortion of the components. Aluminum and iron are almost unsoluble regarding each other in the solid state. Due to this low solubility, the formation of intermetallic compounds occurs, which are characterized by hard and brittle phases. As a result, the strength and the fatigue behavior of the weld seams is degraded, and premature failure of the weld seams occur (Steiners, 2011; Staubach, 2009, Radscheit, 1997). Depending on the aluminum content in the weld pool, various $Fe_xAl_y$ structures, for example $Fe_3Al$ (Al: 25 at.%), FeAl (Al: 50 at.%), $FeAl_3$,( Al: 74 - 76 at.%) and $Fe_2Al_5$ (Al: 69.7 - 73.2 at.%), are formed. Since the aluminum-rich intermetallic phases have a comparatively high hardness of about 1000 HV, they also have a low forming capacity and high susceptibility to cracking (Radscheit, 1997).

### *2.2. Steel-aluminum dissimilar joints*

Mechanical and thermal joining technologies are used to join steel to aluminum. Clinching and riveting (Brüdgam et al., 2004; Simon, 2007), as mechanical joining technologies, are often combined with adhesive methods (Friedrich, 2013). Clinching or riveting are used for fixing the parts during the hardening of an adhesive based on epoxy. The brazing processes, for example arc brazing (Trommer, 2011), inductive brazing (Roulin et al., 1999) and laser brazing (Nothdurft el al., 2015) belong to the thermal joining technologies. To realize a brazing process for steel and aluminum, the steel has to be coated with zinc and the oxide layer on the aluminum surface