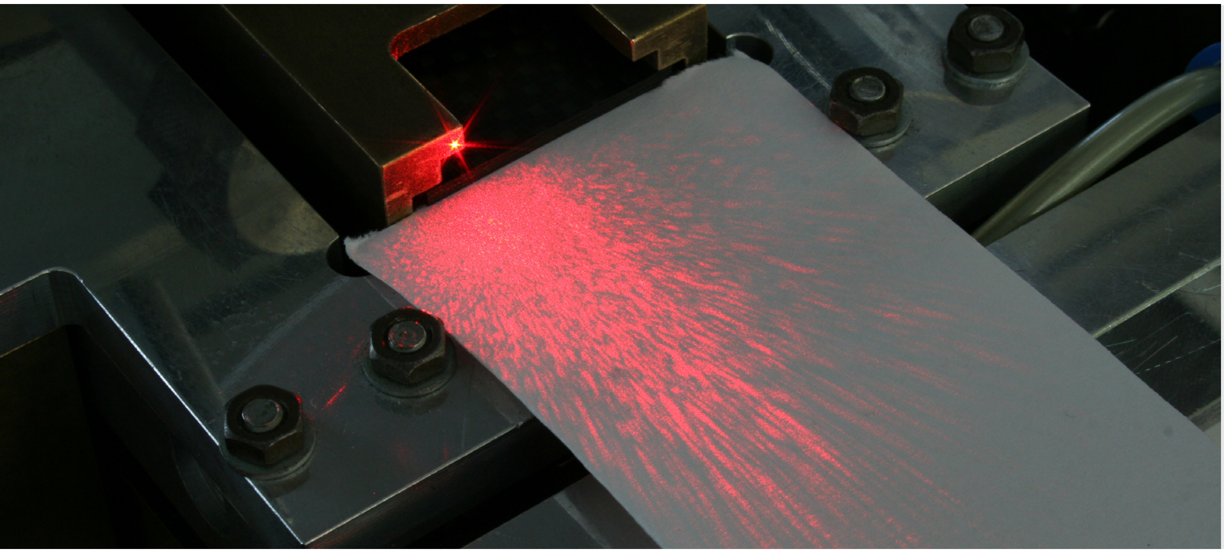
Innovative Bonding Techniques



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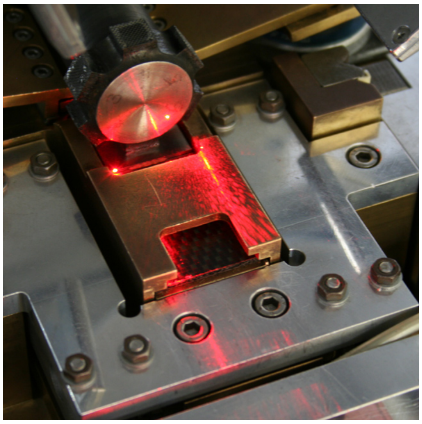
Characterization of the Ultrasonic Welding Process through High-resolution Laser-Doppler Vibrometry

Introduction

A key issue in automotive engineering is to reduce the mass of vehicles and components through innovative materials, their combination and the use of new types of bonding technology. The current demand for lightweight constructions leads to an increasing application of materials like light metals, fiber reinforced composites, ultra high strength steels and their combinations.

The Institute of Materials Science and Engineering (WKK) of University of Kaiserslautern works on new types of welding techniques for light construction materials. At this, ultrasonic welding is of particular importance as an innovative pressure welding process. An ultrasonic welded joint is formed by a high-frequency relative movement between the parts to be joined at a frequency in the range of 20 kHz. Important advantages of the process include extremely short welding times, a low thermal impact on the materials being joined, a high level of environmental compatibility, and a straight forward path to automation and high throughput.

Non contact measurement systems are especially suitable for "on-line" characterization of the high dynamic ultrasonic process. While displacement measurement using capacitance is a possibility, optical measurement systems using lasers have significant advantages. Access to the components to be joined is often difficult due to their small dimensions. Laser measurement systems can easily adapt to these tight conditions since the light can be delivered through flexible fibers that can be focused at the measurement point. Realizing these advantages is why WKK prefers to use Laser-Doppler Vibrometry (LDV) using fiber-optic delivery and collection. Furthermore, by the usage of a two-fiber differential laser vibrometer (OFV-552), relative velocity and displacement amplitudes can be determined across the entire frequency spectrum. In Figure 1, the experimental setup is shown which is used to control and analyze the welding process. In addition to measure and control the essential process parameters such as welding force and energy, the ultrasonic oscillation is determined over time in high resolution for selected joints using the displayed vibrometer system.



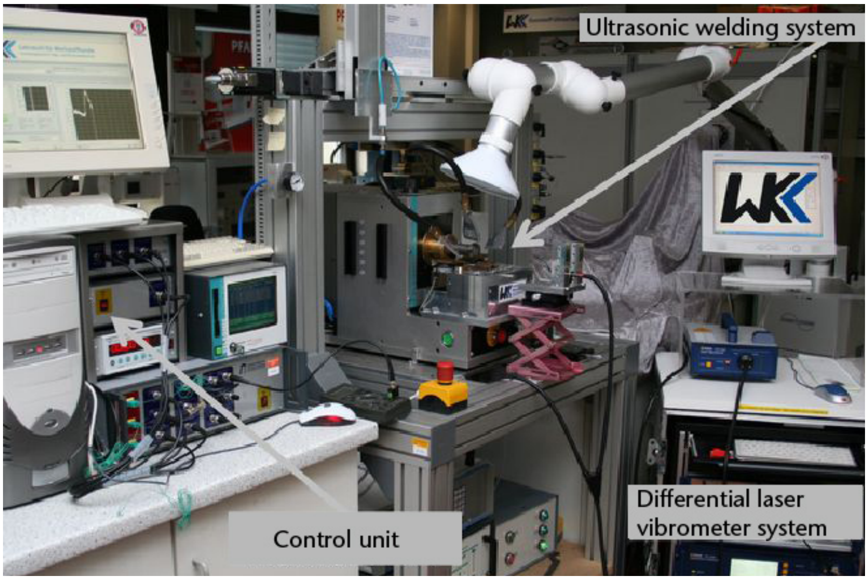


Figure 1: Ultrasonic welding system with differential laser vibrometer.

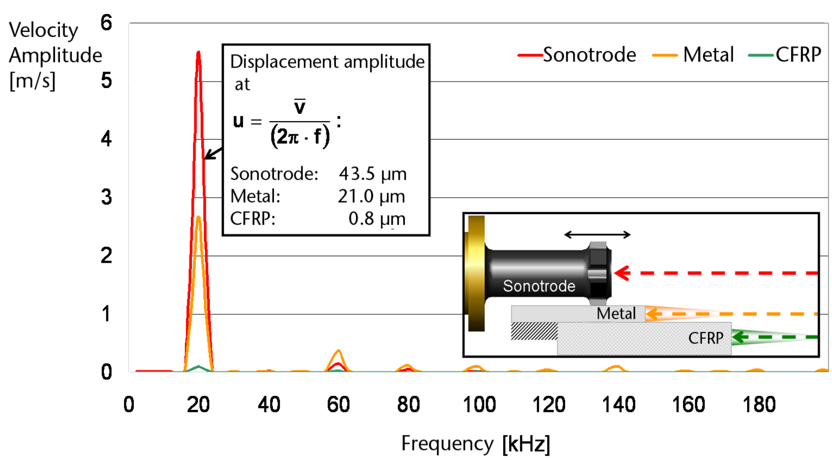


Figure 2: Frequency spectrum of the velocity amplitude during ultrasonic welding of metal/CFRP-composites.

Using of Laser Doppler Vibrometry to Characterize the Ultrasonic Welding of Carbon Fiber Reinforced Polymer (CFRP) Composites

Within the framework of a project supported by the German Research Foundation (DFG), it has been possible to prove that using ultrasonic welding processes can lead to highly durable bonds between light metals and CFRP sheets.

The bonding zone of these materials is formed in two steps in less than five seconds by ultrasonic welding. First, high-frequency transverse oscillation leads to plastification and local extrusion of the polymer matrix of the CFRP from the bonding zone. Then, the ultrasonic oscillation realized a weld between the metal sheet and the load-bearing fibers of the composite without damaging the textile. In this way, tensile shear strengths of up to 50 MPa were realized.

A sufficient relative movement between the components being joined is the critical condition that must be realized to create a highly durable bond.

For a quantitative description of this oscillation, differential LDV was used successfully. In Figure 2, selected results are shown for various components of the welding system as well as for the parts being joined. The relative movements necessary to form the bond have been approximated from single beam measurements and have been experimentally validated with additional two-beam measurements.

Furthermore, the sonotrode was examined in detail during the welding process with regard to a homogenous displacement amplitude distribution. The experimental setup is shown in Figure 3.

For the tests, a star-shaped metal welding sonotrode was selected. The displacement amplitudes were determined using laser interferometry as a function of the working surface of the sonotrodes in contact with the aluminum sheet. The results are shown in Figure 4. In comparison to contact measurement systems, higher displacement amplitudes by about 8% were recorded with the LDV. The difference in measured amplitudes is due to the mass loading of the sonotrode by the contact sensors and the mass inertia of the sensor.

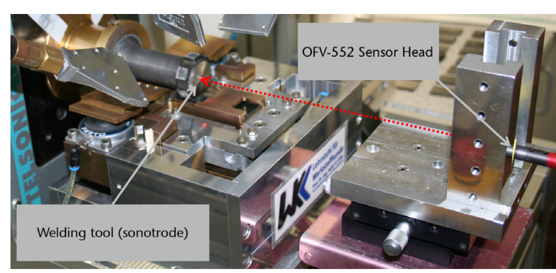


Figure 3: Experimental setup to determine the amplitude distribution on the welding tool.

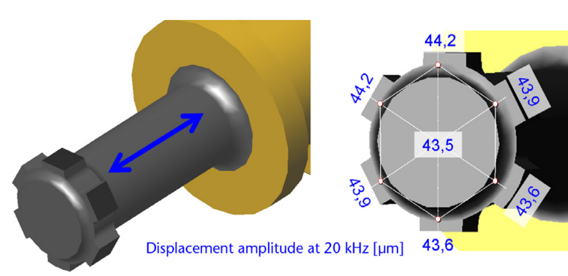


Figure 4: Amplitude distribution of the metal welding sonotrode during the joining process.

The results of the examination show that the oscillation amplitudes of the working surfaces at all six sonotrode working areas in comparison to the amplitude at the center of the sonotrode (u = 43.5 µm) are formed homogeneously and reproducibly.

The LDV is an excellent measurement tool that allows the oscillation amplitudes to be reliably determined under operating conditions and can be used to evaluate the ultrasonic welding process in detail.

Summary and Conclusions

Carried out during the ultrasonic welding process, the oscillation testing using differential Laser Doppler Vibrometry realized a quantitatively correct picture of the high-frequency bonding process. Several significant advantages of Laser Doppler Vibrometry, including small focus spots, high-resolution displacement measurement, zero mass loading, high bandwidth, and relatively long standoff distances, make in-situ oscillation measurement possible during an ultrasonic welding process.

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