Determination of phases and residual stresses in laser beam welded joints of cemented carbide to steel

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Cemented carbides are multiphase materials composed of refractory metal carbides e.g. WC, TiC embedded in a metallic binder (Co, Ni, Fe). Due to their high hardness and superior wear resistance, cemented carbides are used in the production of tools for cutting, machining and milling. Because cemented carbides are brittle and expensive materials, it can be favourable to join them to steel substrates, e.g. in case of saw blades for wood machining applications, where cemented carbides are used as saw tooth tip. Welding of dissimilar materials such as steel and cemented carbides (hardmetals, cermets) is particularly challenging because mismatches in their thermal expansion coefficients and thermal conductivities result in build-up of residual stress as well as the formation of brittle intermetallic phases (e.g. M₆C and M₁₂C) at the cemented carbide/steel interface due to the diffusion of C from the cemented carbides into the steel [1]. Laser beam welding (LBW) of cemented carbides to steel appears as an attractive technique to conventional brazing processes due to its high precision, high process speed, low heat input and the option of welding without filler. So far exclusively joints between cemented carbides with WC concentrations above 88 wt.-% WC and without mixed carbide additions were studied [2-4].

The aim of this study is a first spot check on the possibility of joining steel to cemented carbides with a wider range of WC and mixed carbide contents and controlling η-phase formation by nitridation of the cemented carbides. We employed a three-step laser welding process, which includes pre-heating, welding, and post-heating in order to minimize temperature gradients, thus aiming at reducing residual stress magnitude due to decreasing temperature gradients and avoiding crack formation in the cemented carbide-steel joints.

Different cemented carbide compositions covering a wide range of technical applications according to ISO 513:2004 were compared e.g. a hard metal/steel to a nitrided hard metal/steel weld as well as hardmetal/steel and cermet/steel welds. Nitridation was carried out at 1350°C under nitrogen-rich atmosphere. The cemented carbides were welded to low alloyed hypoeutectoid steel (1.1231: 0.72%C, 0.2%Si, 0.55%Mn, 0.03%P, 0.02%S) by using a Nd:YAG laser source in continuous wave mode operating with a maximum output power of 1.0 kW. X-ray diffraction (XRD) measurements were performed in the fusion zone of the cemented carbide/steel joints. Residual stress distributions in longitudinal and transverse direction were determined across the weld from the steel towards the cemented carbide side. Residual stress measurements by the sin²ψ-method [5] were performed using synchrotron radiation at the experimental station G3 with energy at 6.9keV, area of incidence 1mm×1mm, ψ range 0° to 63°, step size ±0.2 in sin²ψ. The Fe (211) reflection and the WC (201) reflection were chosen in the steel and the cemented carbide, respectively.
A main characteristic of the laser beam welded cemented carbide/steel joints are their narrow, homogeneous weld beads (Fig.1). In case of high heat input, occasionally steel melt can be observed on top of the cemented carbide. The fusion zone extends deeper into the steel part than into the cemented carbide. The heat affected zone (HAZ) in the steel part can be as wide as 1mm and mainly contains martensite. In contrast, the HAZ in the cemented carbide part is about 100µm. In the hard metal/steel and nitrided hard metal/steel joints, the steel part neighbouring the fusion zone contains cells of ferrite, martensite and retained austenite embedded in a very fine network of η-phase, which was identified as a mixture of Fe3W3C and Fe2W6C, although the presence of FeW3C and Fe7W6 was also observed (Fig.2). As for the nitrided cermet, no η-phase concentrations appear at the interface between the cemented carbide and the fusion zone, as revealed either by SEM and X-ray diffraction (Fig.2). The residual stresses for the cemented carbides were measured in WC while the values for the fusion zone and the steel are phase specific residual stresses of α-Fe. Similar residual stress distributions were obtained for all samples (Fig.3). The WC phase in the cemented carbide in all samples is under compressive residual stresses with values in the range between -250 MPa and -400 MPa. The steel in the fusion zone, the heat affected zone, and base material is generally under tensile residual stresses. In the fusion zone of the nitrided hard metal/steel joint, tensile residual stress values of 300 MPa both in welding direction and perpendicular to the welding direction were obtained whereas the value in the nitrided cermet is 52 MPa and even in compression as low as -460 MPa in the welding direction. In the heat affected zone in steel, values of about 400MPa were obtained for the hard metal joint in both directions, whereas in the cermet joint, tensile stress in the welding direction amounts to 190MPa. Residual stresses in steel in the hard metal joint are usually tensile in both directions (about 250MPa), whereas in the cermet they can be as low as 130MPa in welding direction.

The results reveal that the three step laser beam welding process successfully produced crack-free and non-porous joints. Nitridation of the cemented carbides results in a significant reduction of the amount of brittle phases and residual stresses. Bending tests revealed that the mechanical properties of the joints thus obtained are competitive to those of the conventional brazed steel-cemented carbide joints [6].

References

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