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Induction brazing of cermets to steel

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Abstract. The paper considers the induction brazing of TiC based cermets with Ni-Mo and Fe-Ni binder phase and Cr_3C_2 based cermets with Ni binder to structural and stainless steels under vacuum and air conditions. Commercially available traditional filler metals and experimental amorphous filler foils were tested. Possibility of mechanical metallizing of cermet surfaces with rotating Ti brushes prior to the brazing process was studied. Increase in the surface roughness after mechanical metallizing and non-uniform distribution of Ti on the treated surfaces were observed. Positive influence of electrochemically deposited Ag and Ni coatings on the shear strength of joints was found when optimal filler metals were used. Maximum shear strength up to 200–250 MPa was achieved with Ti- and Ni-based amorphous filler foils. Brazing in air by optimal fluxes and Ag- and Cu-based conventional brazing fillers can be used for brazing of cermets. Shear strength up to 150–190 MPa was achieved. The shear strength of vacuum brazed joints increases with the increase of the metal binder content in the cermet. Diffusion of the filler metal to base metal and to joint interface was studied by EPMA and SEM. It was found that cermets are successfully brazed with amorphous filler metals and the strength of the joints was not affected by the rapid heating during the induction process and relatively low vacuum.

Key words: cermet, brazing, amorphous filler, coatings, metallization.

1. INTRODUCTION

Cermets, based on titanium and chromium carbides, have low density, relatively high strength and wear resistance and also high oxidation and corrosion resistance and therefore they can be successfully used in wear resistant structural components. When abrasion is combined with oxidation or chemical corrosion, the chromium carbide cermet is highly superior to tungsten carbide hardmetal [1]. TiC-based cermets, cemented with Ni or steel binder phase, applied in metal cutting and forming operations [2], have been found to be superior over tungsten carbide based hardmetals. TiC-Ni cermets, produced by self-propagating high temperature synthesis, can be used for valves, tappets in engines, seals or bearings [3–5].

To save expensive carbide composites and to simplify the design of complicated tools and wear resistant components and to reduce the manufacturing costs, bimetallic ”cermet + steel” compounds can be used. Durability of such bimetals depends on their mechanical strength and internal residual stresses of the joints. Diffusion welding can be successfully used for bimetallic “cermet + steel” compounds as a shear strength up to 300 MPa can be achieved [6]. In cutting tools production and in other applications, brazing as a bonding technique has been commonly used. However, information concerning the brazing of cermets to steel is comparatively restricted [3–8].

The shear strength of the 60%TiC + 40%Ni cermet, vacuum brazed with Ag-Cu-Zn filler metal to structural steel, was reported in [3–5]. By increasing silver content in the brazing filler metal (FM) from 23% to 46%, the shear strength increased from 95 up to 120 MPa. The mechanical properties of the joints were very sensitive to the brazing temperature and time and a 2 to 3 times decrease of them occurred when optimal parameters were not used. In [7] the shear strength of the joints “TiC-based cermet + steel” was studied and a maximum shear strength of up to 110–130 MPa was achieved when an amorphous filler metal was used [7]. Some preliminary results, related to the shear strength of the chromium carbide based cermet, vacuum brazed to steel, are reported in [8].

The brazing of two different materials, such as cermet to steel, is apt to present numerous difficulties arising out of differences in their chemical, physical and mechanical properties. To achieve the required properties of the joints (strength, corrosion or oxidation resistance) in specific service areas, the most important factors are the selection of the optimal filler metal and process parameters (heating method, brazing atmosphere, fluxes, temperature and time). To ensure the oxidation and corrosion resistance of brazed joints, Ni- and also Ag-based filler metals are usually recommended. New amorphous filler metals (AFM), produced by rapid solidification technology, are prospective due to their chemical composition. The industrial application of these materials is still limited [9]. To ensure high quality of the joints, relatively high vacuum (10^{-2}–1.3 Pa) [10] or protective atmosphere (Ar, N_2, Ar/H_2) must be applied during brazing.

Thin coatings of Ni or Cu interlayers [7] on the faying surfaces of TiC-based cermets can protect the surfaces and improve wetting. A significant increase, from 17% to 70%, in the shear strength of brazed joints for one cermet grade was observed. For other grades the effect of the Ni coating was negative, as the shear strength decreased by about 22%–25%.

Filler metals, containing titanium or Ti coatings, were used for brazing ceramics because their properties improve the wetting of ceramics [11–13] and reduce the oxidation of faying surfaces. Such coatings are attractive also for brazing of the cermets. After mechanical metallization of ceramics, conventional and inexpensive filler metals can be used [12–13].

In many applications of brazing, induction heating is a faster and more efficient technique than traditional vacuum furnace heating.

This paper aims to demonstrate the feasibility of induction heating for vacuum and air brazing of chromium and titanium carbide based cermets with traditional and amorphous filler metals. Focus is also on the effect of thin coatings on the performance of joints „cermet + steel".

2. MATERIALS AND EXPERIMENTAL PROCEDURE

The study focuses on the joints, based on chromium carbide base cermets with Ni binder and titanium carbide base cermets with Ni-Mo and Fe-Ni steel binder phase (Table 1). Hardmetal on the basis of WC with 15% Co-binder (Table 1) as a reference material was also tested. The mean grain size of carbides of the TiC-based cermets was 2.0–2.2 µm and of the Cr_3C_2-based ones 3–4 µm. Specimens with the diameter of 18.0–19.6 mm and height of 10 mm were used.

Carbon structural steel grade C 45 (0.45 wt% of carbon) and austenitic stainless steel grade X10CrNi18-8 (1.4310) were used as counterparts. The diameter of the counterparts was 20 mm and the height was 50 mm. The cermet and steel counterparts to be bonded were ground to surface finish of $R_a \leq 1$ µm.

Brazing filler metals were selected (see Table 2) taking into consideration the wetting ability of carbides as well as oxidation and corrosion resistance. To ensure high oxidation and corrosion resistance, especially for stainless steel-cermet joints, nickel and silver based brazing alloys are preferred, but they are rather expensive. Cheaper copper based filler metals, successfully used for the brazing of TiC cermets to steel [7], were also used.

Table 1. Chemical composition and properties of the cermets

Grade	Carbide content, wt%	Binder composition, wt%	Density, g/cm³	Hardness, HRA	Transverse rupture strength R_{TZ}, MPa	Oxidation rate*, mg/cm²
HA15	WC, 85	15%Co	13.9	87	2800	20
TiC50/NiMo	TiC, 50	Ni + 20%Mo	6.4	87	2300	0.25
TiC60/FeNi	TiC, 60	Fe + 8%Ni martensitic steel	6.6	88	2200	–
CrNi10	Cr_3C_2, 90	Ni 90	6.8	91	750	0.04
CrNi30	Cr_3C_2, 70	Ni 70	7.2	86	1200	0.08

* Weight gain rate at 800 °C, 2 hours.

Table 2. Chemical composition of filler metals, brazing conditions and temperatures

Grade	Type	Composition	Brazing conditions	Brazing temperature, °C
S1201	AFM	52Ti-24Cu-12Zr-12Ni	Vacuum	900
S1204	AFM	28Ti-72 Cu	Vacuum	900
S1311	AFM	70Ni-16Co-5Fe-4Si-4B-0.4Cr	Vacuum, air	1020
MBF20	AFM	82Ni-7Cr-4Si-3B-3Fe	Vacuum	1070
Argo-Braze 49H	FM	49Ag-16Cu-23 Zn-7.5Mn-4.5Ni	Air	750
LAg72	FM	72Ag-28Cu	Vacuum	830
F-Bronze	FM	57.5Cu-38.5Zn-2Mn-2Co	Air	980

For vacuum brazing, four different amorphous filler metal foils with the thickness of 50 μm were selected. The amorphous filler metals, containing titanium (grades S1201 and S1204), are compatible with the carbide phase of TiC-cermets and Ni-based filler metals (grade S1311) with the binder phase cermets. Ni-Co-Fe-Si amorphous filler metal (grade S1311) was specially developed for vacuum brazing of tungsten carbide based hardmetals [10]. Ni-Co based amorphous filler metal grade MBF20, produced in large volumes [9], was tested for brazing of TiC-based cermets to steel [7].

Traditional brazing filler metals were selected from the production list of commercially available alloys, developed for brazing of WC-Co hardmetals, especially for impact loadings (Table 2). Three grades of brazing fluxes were tested and an optimal brazing flux grade F125 was selected.

Some CrNi30 and TiC50/NiMo specimens were metallized with titanium at Julich Research Centre (Germany). Specimens were clamped to the spindle of a lathe by a chuck. The rotating Ti brushes passed the surface of the cermet and due to the wear of brushes coated them with a film of titanium. The mean thickness of the coatings was 5 μm. A portable electrochemical metallizing system was used to deposit the 10 μm thick Ag or Ni coating on the cermet surface.

The brazing processes were conducted in the special equipment UDS-4 in vacuum (0.8–1.0 Pa) or in the air environment (Fig. 1). The foils of amorphous filler metals with a thickness of 50 μm and traditional filler metals with a thickness of 150 μm were placed between the cermet-steel parts under low pressure (2–3 MPa) and were induction heated for 1 min. The pressure, applied to the specimen, was achieved by a hydraulic system. Joints were heated by the induction heating (440 kHz) generator.

To estimate joint strength, the shear strength of bimetallic specimens was determined by a special device. A minimum of three tests were carried out for every experiment to ensure the confidence interval of 15% with the probability factor of 95%.

The distribution of chemical elements in the bonding zone was examined by the electron probe X-ray microanalysis (EPMA) and fracture surfaces were

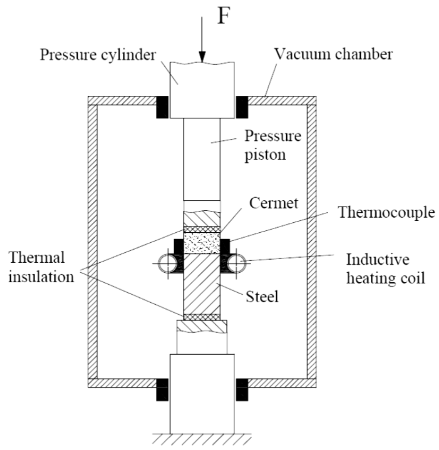

Fig. 1. Schematic diagram of a vacuum bonding hot press.

studied by SEM (Zeiss EVO MA-15). Roughness of the surfaces of mechanically metallized cermets was described using the authentic mean values (R_a, R_z,) and maximum roughness (R_{max}). A laser-based profilograph of the Mahr company was used. The roughness measurements of the specimens were carried out in two perpendicular directions.

3. RESULTS AND DISCUSSION

3.1. Characterization of the coatings

The mean results of mechanically metallized surface roughness measurements of Cr_3C_2 - and TiC-based cermets are given in Table 3 and SEM photographs of metallized surfaces are presented in Fig. 2.

The results in Table 3 show that after mechanical metallization the surface roughness was increased, particularly the parameters R_z and R_{max}. In the process of mechanical metallization, spreading of Ti on the tops of surface asperities and a non-uniform distribution of Ti were revealed (Fig. 2). The distribution of the surface roughness was not uniform in the radial direction of the specimens.

Table 3. Characteristics of mechanically metallized surfaces

Parameter, µm	Before metallization	After metallization	
		Average	In the centre of the sample
R_a	0.65	1.06–1.28	1.40
R_z	6.67	10.4–13.4	13.5
R_{max}	7.15	12.2–13.2	21.6

(a) (b) (c)

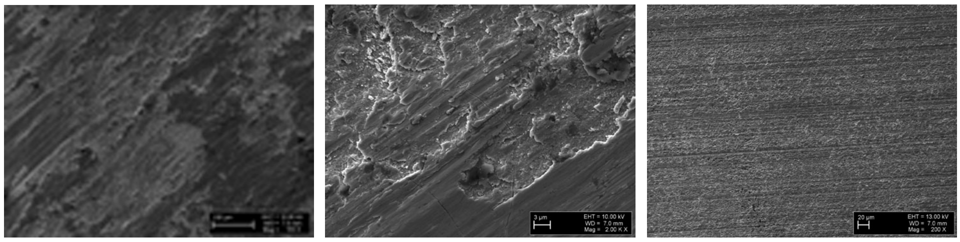

Fig. 2. SEM photographs of the metallized surface: (a), (b) mechanically metallized Ti-coating; (c) electrochemical Ni coating.

3.2. Shear strength of joints

3.2.1. Chromium carbide based cermets

The shear strength of chromium carbide based cermets, brazed in vacuum with AFM joints, is given in Fig. 3a. The maximum strength of 350 MPa is achieved with amorphous Ti-based composition S1201. Lower strength was observed, when the brazing process was carried out in vacuum and Ni-based amorphous filler metal grade S1311 was used. Fracture of the joints occurred in the central part of brazed joints, which confirms a good wettability of the cermet. Results of testing a cermet, containing 10% and 30% Ni-binder, indicate that an increase in the nickel content in the cermet results in the increase of the shear strength of vacuum brazed joints, confirming the dominating role of the binder phase content of the cermet to the mechanical properties of joints. Results also demonstrated a significant influence of the brazing atmosphere on the strength of brazed joints when amorphous filler metals were used. In the case of air brazing (Fig. 3b), with an amorphous Ti-based filler metal, shear strength was about half as high as that of the brazed one in relatively low vacuum. Oxidation of the cermet surface in fracture surfaces was observed.

Brazing with traditional filler metals in air (Fig. 3b) showed that brazing with Ag-based traditional filler metals provides minimal satisfactory results for the production of wear resistant parts (75 MPa). Air-brazed joints with Cu-based filler metal (grade F-Bronze) have very low strength. Electrochemical deposition of a Ni coating to the cermet surface was found to improve wetting of the cermets and an increase of the shear strength of the joints up to 205 MPa, using Ag-based filler metal. Silver coating on the cermet surface improved the shear strength of the joints significantly when a Cu-based filler metal was used. Mechanically deposited Ti coating was found to have negative influence on the strength of brazed joints, as only 40 MPa shear strength was achieved. Our experiments showed, that chromium carbide based cermets can be successfully brazed to stainless steel by use of Ag-based (grade Argo-Braze 49H) and also Cu-based (F-Bronze) traditional filler metals and practically the same level (140 MPa) of shear strength can be obtained when optimal fluxes are used.

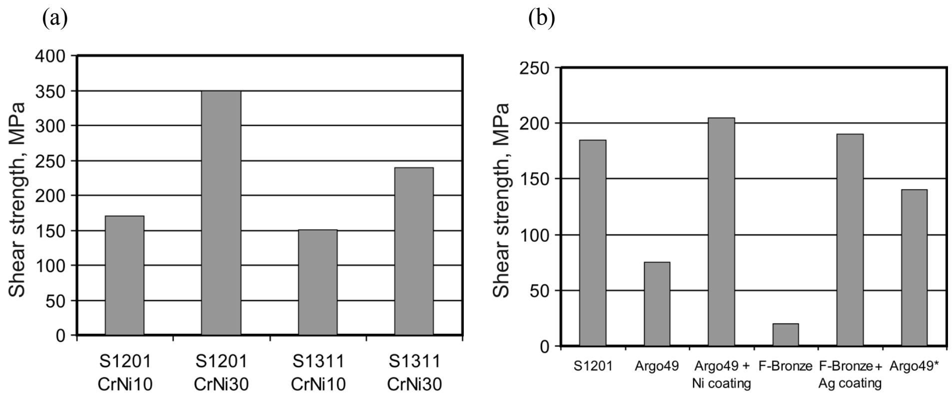

Fig. 3. Shear strength of joints "chromium carbide-based cermets + steel": (a) brazing in vacuum, counterpart–structural steel; (b) brazing in air, counterpart–structural steel, * counterpart–stainless steel.

3.2.2. Titanium carbide based cermets

Figure 4 a shows the shear strength of TiC60/FeNi cermet, brazed in vacuum using different amorphous filler metals. The shear strength of air brazed TiC50/NiMo cermet and WC-Co hardmetal as reference material is shown in Fig. 4b.

Maximum strength of the brazed joints is provided by brazing in vacuum. The most prospective amorphous filler metals for joining TiC-based cermets are of the Cu-Ti type (grade S1204) and the Ni-Co-Fe type (grade S1311), which gave the shear strength up to 260–300 MPa. The chemical composition of amorphous filler metal grade S1204 is more compatible with the basic component (TiC) of a cermet, and the grade S1311 – with the binder phase. A small decrease in the

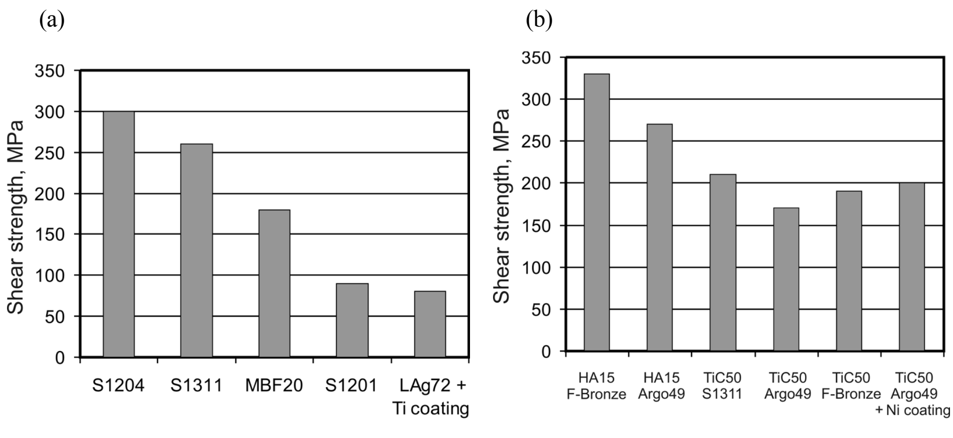

Fig. 4. Shear strength of TiC-based cermets and reference WC-based hardmetal, brazed to structural steel: (a) vacuum brazing, cermet TiC60/FeNi; (b) air brazing, cermet TiC50/NiMo and hardmetal HA15.

shear strength of brazements was observed when the joining process with amorphous filler S1311 was carried out in the air (Fig. 4b). It can be pointed out that the shear strength of "TiC-cermet + steel" joints, brazed in vacuum with amorphous filler metals (Fig. 4a), is comparable to that of "hardmetal + steel" joints, brazed in air with traditional filler metals (Fig. 4b).

For brazing TiC-based cermet in the air atmosphere, an Ag-Cu based traditional filler metal with optimal fluxes should be used and the shear strength up to 190 MPa can be achieved (Fig. 4b). Such strength is sufficient in many applications.

The influence of electrochemical coatings on the strength of brazed joints was contradictory. Nickel coating with the combination of Ag-based filler metal showed a small improvement in the strength of air brazed joints (Fig. 4b). Ag-coated cermets, brazed with Cu-based traditional filler metal, showed low strength (40 MPa). No positive effect of Ti coating (mechanical metallization) on the strength was revealed when traditional Ag-Cu filler metal (grade LAg72) was used (Fig. 4a) and the process was carried out in vacuum.

For the production of cutting and metalforming tools, working in heavy service conditions, the first choice for TiC-based cermets are Cu-Ti- and Ni-based amorphous filler metals grades S1204 and S1311, respectively. For the production of bimetallic structural parts, the F-Bronze and Argo 49 traditional filler metals can also be used. A lower brazing temperature of the Ag-based filler metal (compared to the Cu-based one) reduces the magnitude of internal stresses in the brazed joints and this filler metal is expected to be favourable, when reliability of joints is of importance.

3.3. Microstructure and fractographical analysis

Figure 5 shows the microstructure and element line-scans of vacuum brazed joints "Cr_3C_2-cermet + steel" (a) and "TiC-cermet + steel" (b) using Ni-based amorphous filler metal grade S1311. In the case of "TiC-cermet + steel" (Fig. 5b) a smooth diffusion penetration of Ni from the molten filler to the cermet and steel interface and an intensive iron diffusion from the steel to filler metal can be observed. According to the fractographical analysis, the joint fractured during testing usually in the zone close to the filler metal–cermet interface. TiC particles float from the cermet into the brazing zone (Fig. 5b).

In the case of joints "Cr_3C_2 + steel" (Fig. 5a) intensive diffusion of nickel to cermet–steel interface and steel counterpart can be observed. In contrast to brazing of TiC-based cermets (Fig. 5b) smooth diffusion of iron to cermet is observed. The weakest area of joints is the diffusion zone close to the cermet in central area of the joint.

Fractographical SEM examinations proved that the strength maximum, as usual, corresponds to cases when the fracture occurs close to the filler metal central zone. Lower strength of joints, brazed in the air atmosphere, is connected with the fracture of joints at the interface "cermet–filler metal". It indicates that

(a) (b)

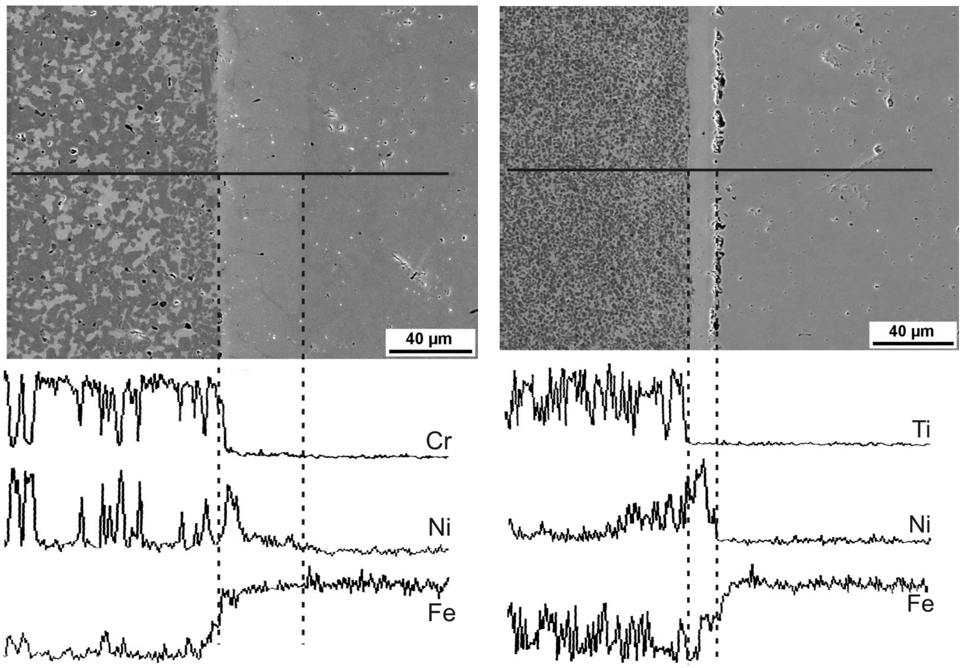

Fig. 5. Structure and element distribution of vacuum brazed joints using amorphous filler metal S1311: (a) CrNi30 cermet; (b) TiC50/NiMo cermet.

wetting of carbides in the cermets and diffusion between the contacting surfaces of the carbide composite-filler metal was insufficient.

It should be mentioned that fast induction heating could cause inhomogeneous heating of steel and cermet parts. During induction heating the temperature in the pheripherical parts of specimens is higher than in the central part. In some cases of air brazing even black discoloration rings with a diameter of 2–3 mm were observed, indicating extensive oxidation of this area. As in the central area of specimens the temperature is the lowest, not all the filler metal is molten, wetting of the surfaces is insufficient and therefore pores and flux inclusions are not fully removed.

4. CONCLUSIONS

4.1. Cr_3C_2-cermets

- The highest strength of the joints is achieved using the Ti-based brazing amorphous filler metal (grade S1201). Vacuum brazing is preferable to air brazing.

- The higher the binder content in the cermet, the higher shear strength of the joints can be achieved.
- Air brazing with traditional Ag- and Cu-based filler metals gives best results when metallization of the cermet with Ag and Ni is carried out before brazing.
- Air brazing with Cu-based Cu-Zn filler metal and Ag-based Ag-Cu filler metal enable to achieve satisfactory results only in brazing of "Cr_3C_2-cermet + stainless steel" joints.

4.2. TiC-based cermets

- The strength of joints "TiC-based cermet + steel" in conditions of vacuum brazing is comparable to that of "WC-based hardmetal + steel" joints when using amorphous filler metals (grades S1204, S1311).
- TiC-based cermets can be brazed with good results in air using traditional Cu- and Ag-based filler metals and the shear strength of joints up to 200 MPa can be achieved.
- Preliminary metallization with Ti and Ag does not increase the strength of the joints "TiC-based cermet + steel".

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Kermiste induktsioonjootmine terasega

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Töös uuriti TiC-baasil Ni-Mo ja Fe-Ni sideainega ning Cr_3C_2-baasil Ni sideainega kermiste induktsioonjootmist konstruktsiooni- ja roostevaba terasega nii vaakumis kui ka õhu käes. Joodisena kasutati nii tavapäraseid tööstuses kasutatavaid kui ka eksperimentaalseid amorfseid joodiseid. Uuriti kermiste pinna märguvuse parandamise ja liite tugevuse suurendamise võimalust, kasutades nii tavapärast galvaanilist (elektrokeemiliselt sadestatud) kui ka uudset mehaanilist pindamist pöörlevaid Ti-harju kasutades. Vaatluse all oli samuti märguvust parandava pindamise mõju kermise pinnakaredusele. Uuringud näitasid, et elektrokeemilised Ag- ja Ni-pinded parandasid märgatavalt liidete "kermis + teras" nihketugevust sobivate joodiste kasutamisel. Liidete maksimaalne nihketugevus 200–250 MPa saavutati jootmisel vaakumis sobivaid Ti- ja Ni-baasil amorfseid joodiseid kasutades.

Kvaliteetseid jooteliiteid (liite nihketugevus 150–190 MPa) on võimalik saada samuti õhukeskkonnas jootmisel, kasutades sobivaid räbusteid ja Ag- ning Cu-baasil tavajoodiseid. Jooteliidete "kermis + teras" tugevus sõltub sideaine sisaldusest kermises, olles seda suurem, mida suurem on karbiidkomposiidis oleva metalse faasi osakaal. Liidete "kermis + teras" mikrostruktuuri uuringuteks kasutati elektronsondmikroanalüüsi (EPMA) ja jooteliidete purunenud pindade analüüsiks skaneerivat elektronmikroskoopiat (SEM).