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Structure and stresses in high dimension brazed joints of cermets and steel

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ABSTRACT

Purpose: of this paper is description of stresses in brazing joints of different physical and mechanical properties and evaluation of microstructure and mechanical properties of large dimensional vacuum brazed joints of WC–Co (ISO K05), Fe-TiC sinter plates (Ferro–Titanit Nicro 128) and precipitation hardened stainless steel of 14-5 PH (X5CrNiMoCuNb14-5) using copper as the brazing filler metal.

Design/methodology/approach: Microscopic examinations with the use of scanning electron microscope were performed to establish microstructure of the joint. Shear strength R_t and tensile strength R_m of the joints have been defined.

Findings: It have been state, that the basic factors decreasing strength of the joint, which can occur during vacuum brazing of the WC-Co, Fe-TiC sinters - Cu brazing filler metal - 14-5 PH steel joints are diffusive processes leading to exchange of the cermets and brazing filler metal elements. They can have an unfavourable influence on ductility and quality of the joint..

Research limitations/implications: Results of numerical calculations of three-dimensional models of cermets and steel brazed joints stresses are presented. Particular attention was paid to stresses occurring in joints of large brazing surfaces. It was shown that joints microstructure and mechanical properties depend on chemical composition filler and parent materials, diffusion process during brazing, leading of the cermets and filler metal components replacement as well as joint gap thickness. The thickness of the joints and parent materials have an essential influence on the value of the local stress.

Practical implications: As a result of conducted experiments criteria for generating high dimension coatings of cermets plates brazed to steel. The PM Fe-TiC and PM WC - Co composite plates vacuum-brazed to steel as cutting coatings have been worked out and applied in industry.

Originality/value: An original value of the paper is to prove the tendency of concentration gradients of alloying components and intermetallic phases creation and factors reducing stresses which may occur during vacuum brazing of The PM Fe-TiC and PM WC-Co and corrosion resistance steel.

Keywords: Metallic alloys; Materials; Welding

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MATERIALS

1. Introduction

Creation of stainless steels and cermets joints is an important problem for contemporary welding engineering which has failed to find a completely acceptable solution. Cermets exhibit high hardness and resistance to abrasion wear, but they display low ductility which limits their functionality under dynamic loads. Cermet properties will be useful provided that machine and tool parts are designed so as to either eliminate or reduce the internal tensile stress. To achieve this, a cermet component should be properly supported by means of a special steel element. The joint between steel and cermet elements must demonstrate good mechanical properties and ability to compensate the stress produced by the difference between thermal expansion coefficients of the elements to be joined.

Brazing techniques allow joining materials, which have different properties. Studies concerning physical, chemical, and metallurgical limitation of brazing process are fundamental to the development of this technology and have been regularly published in recent years [1-6].

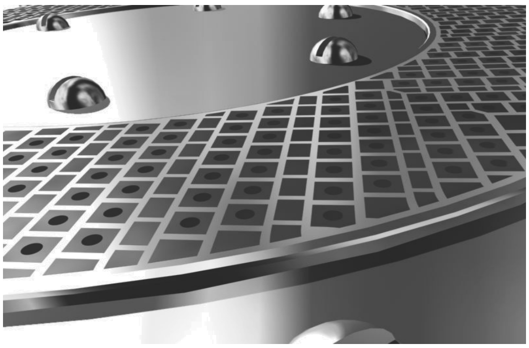

Fig. 1. Wear resistance cermet plates coating on the front of spinneret for granulation polyethylene

Fig. 2. View of a propeller mixer of crushed gravel with the abrasion-resisting layer of a large size surface covered with plates of cermets brazed to the base

Joint gap size is essential among the parameters which have an effect on structure and properties of the jont. Complex nature of the problems connected with steel-cermet joints is specifically evident in the case of large-surface steel elements coated with abrasion resistant cermet plates. Such surfaces are produced on e.g. cutting elements of the spinning nozzles for polymer granulation and propeller mixers of ceramic granulated product (Figs. 1-3), as well as on the components of mills and dry mixer designed for hard input material treatment. In the case of large machine elements made of stainless steels and cermet plates, vacuum brazing is a source of various technical problems, which are less important for other brazing technologies [7,8]. Such problems originate from the requirement to heat up the entire element for a period of time longer than in the case of other brazing techniques. Long brazing time stimulates the diffusion process between the filler metal and the elements to be joined, which often reduces the quality of the joint and create a risk of cracking. In order to reduce the risk of cracking control of residual stresses in the joint is advisable [9-15].

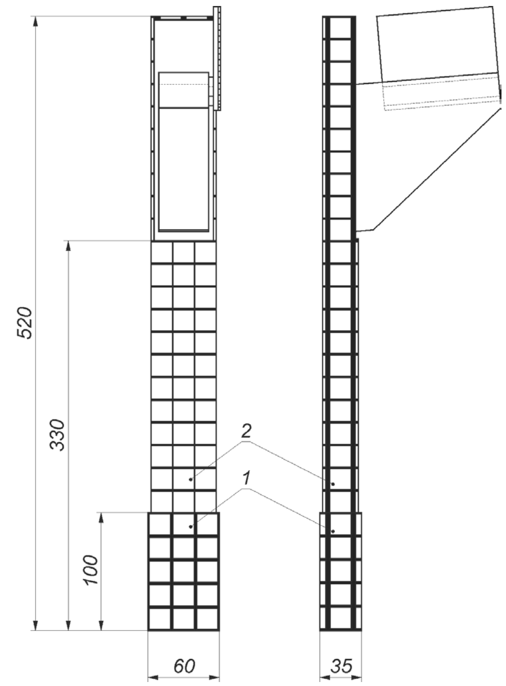

Fig. 3. Scheme of a propeller mixer of ceramic granulated product with the abrasion-resisting layer of a large size surface covered with plates of cermets brazed to the steel frame

2. Joint microstructure and properties

There werFe generating vacuum brazed joints of 10x10 plate (8x8x6mm) of WC-Co (ISO K05), Fe-TiC, and Ferro-Titanit Nicro 128 with precipitation hardened stainless steel 14-5 PH (X5CrNiMoCuNb14-5) (Tables 1-3).

Using copper as the brazing filler metal. The brazing were: temperature 1000°C, brazing duration - 10 and 20 min, joint thickness - 0.05 and 0.10 mm, vacuum as the brazing atmosphere.

Considerably longer period of vacuum brazing when compared with other brazing methods, lack of fluxing agents and necessity of applying volume heating of joining elements produces of significant contribution of diffusion processes throughout brazing process resulting composed joint microstructure.

Table 1.
Chemical composition and properties of 14-5 PH (X5CrNiMoCuNb14-5) steel

Chemical composition %											
Ni	Cr	Mn	Si	Cu	Mo	Nb	Ta	C	P	S	Fe
5.4	13.5	13.5	0.6	1.4	1.5	0.5	1.7	0.07	0.04	0.03	bal.

Physical-mechanical properties					
R_m, N/mm^2	$R_{0.2}$ N/mm^2	A_5, % min.	HRC	λ, W/mK	α $^{10-6}$, K^{-1}
650	598	17	30	17.165	0.771

Formation of brittle intermetallic phases, alternation of solder chemical composition, increase of brazing, and vacuum evaporation processes are possible.

Distribution of chemical elements in the brazed joint are presented on Figs. 4-7. The steel-solder-WC-Co sinter joints, and steel-solder-Fe-TiC sinter joints microstructure have been detailed described in [7].

Table 2.
Chemical composition and properties of WC-Co (ISO K05) sinter

Chemical composition %		Density g/cm^3	Hardness HV30	Bending strength Rg N/mm^2
Co	WC			
15	85	14.0	1150	2400

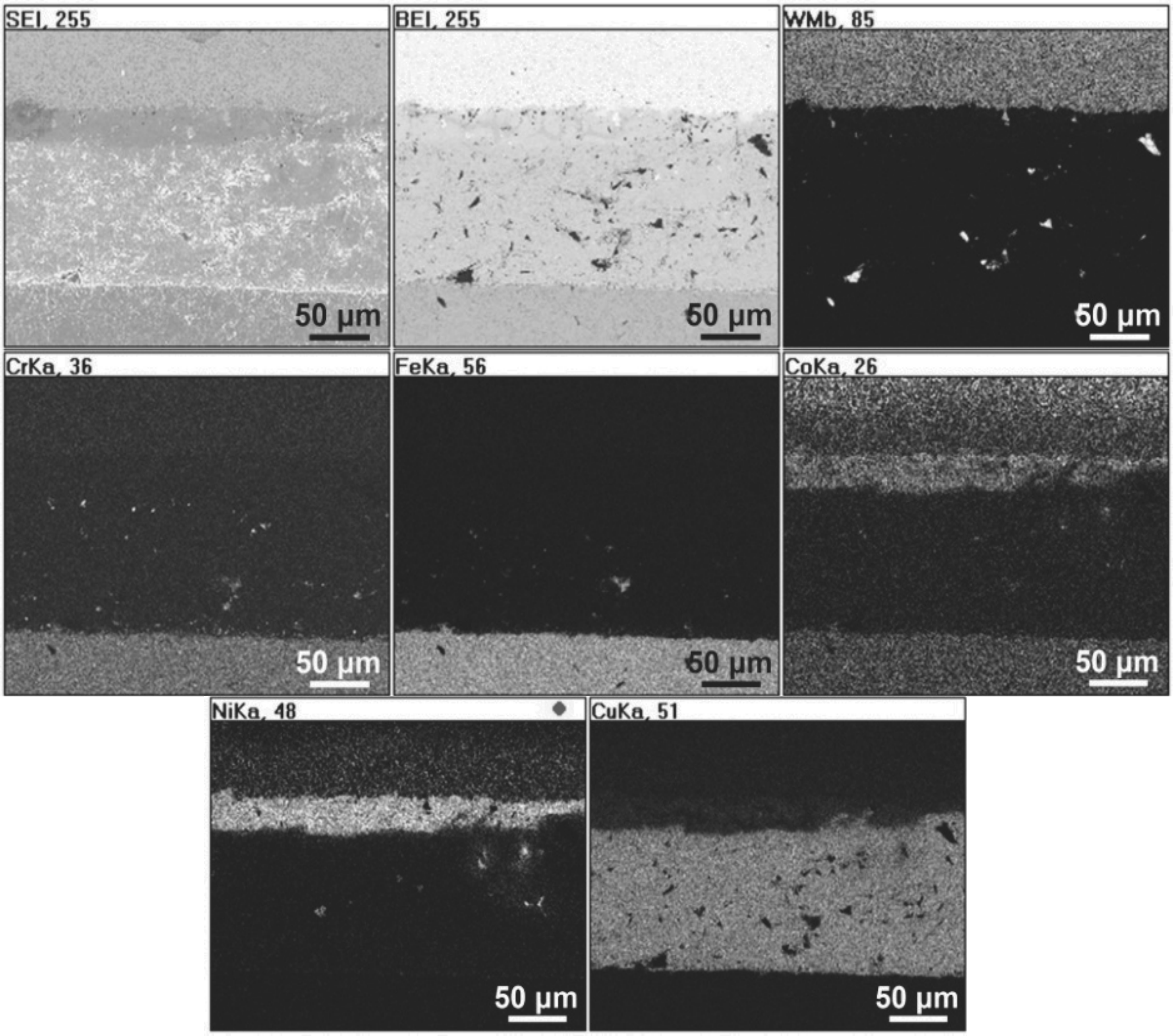

Fig. 4. Distribution of alloying elements in the brazed joint of 14-5 PH (X5CrNiMoCuNb14-5) steel - AWS BCu-1 filler metal - WC-Co (ISO K05) sinter

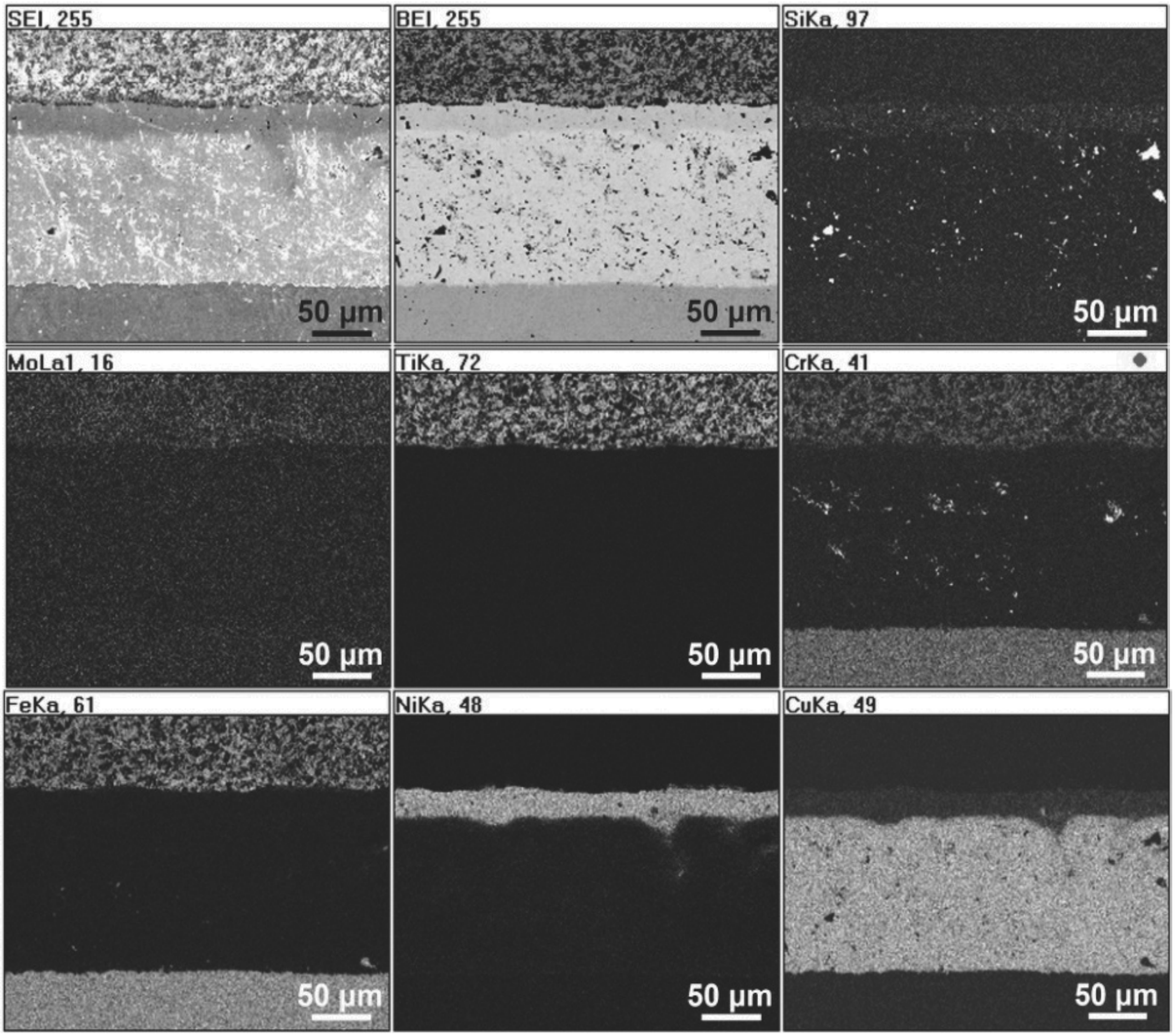

Fig. 5. Distribution of alloying elements in the brazed joint of 14-5 PH (X5CrNiMoCuNb14-5) steel - AWS BCu-1 filler metal - Fe-TiC (Ferro-Titanit Nicro 128) sinter

Table 3.
Chemical composition and mechanical properties of Fe-TiC (Ferro-Titanit Nicro 128) sinter

Chemical composition, %						
Reinforcement	Matrix					
TiC	C	Cr	Mo	Co	Ni	Fe
30.5	-	13.1	5.0	9.3	3.9	bal.
Mechanical properties						
Density g/cm^3	Compression strength Rc, N/mm^2	Bending strength Rg, N/mm^2	Modulus of elasticity E, N/mm^2	Hardness HRC		
6.5	2750	1200	294 000	62		

The joints have multi - zone microstructure with diffusion transient zones in the steel-filler metal and filler metal-cermet-steel boundaries.

Table 4.
Mean values of the brazed joints 14-5 PH - AWS BCu-1- WC-Co shear strength R_t and tensile strength R_m

Brazing duration			
10 min		20 min	
R_t, N/mm^2	R_m, N/mm^2	R_t, N/mm^2	R_m, N/mm^2
Joint thickness 0.05 mm			
157	224	112	196
Joint thickness 0.15 mm			
89	211	78	89

Steel - solder - WC-Co sinters joint is composed of zones:

- WC-Co sinter plates,
- transient zone contained sinter and filler metal constituents,
- Cu based solid solution with WC-Co sinter components,
- transient zone contained steel and filler metal constituents,
- steel matrix.

Steel - solder - Fe-TiC sinters joint is composed of zones,

- Fe-TiC plates,
- Ni diffusion barrier,
- transient zone contained sinter and filler metal constituents,
- Cu based solid solution with Fe-TiC sinter components,
- transient zone contained steel and filler metal constituents,
- steel matrix.

Properties of the joint are also strong influenced by diffusion processes. Shear strength R_t and tensile strength R_m of the joints are higher for steel - solder - Fe-TiC sinter joints with smaller joints thickness and generated in smaller time of brazing (Tabs. 4, 5).

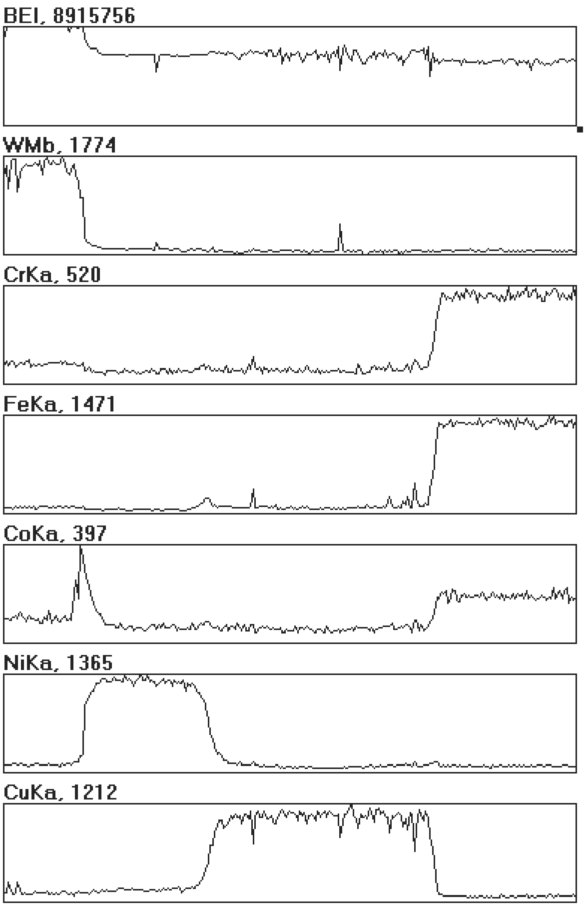

Fig. 6. Distributions of alloying elements in the cross section of brazed joint of 14-5 PH (X5CrNiMoCuNb14-5) steel - AWS BCu-1 filler metal - WC-Co (ISO K05) sinter

Table 5.
Mean values of the brazed joints14-5 PH - AWS BCu-1- Fe-TiC shear strength R_t and tensile strength R_m

Brazing duration			
10 min		20 min	
R_t, N/mm^2	$R_{m,}$ N/mm^2	R_t, N/mm^2	$R_{m,}$ N/mm^2
Joint thickness 0.05 mm			
190	270	165	231
Joint thickness 0.15 mm			
125	242	103	206

3. Stresses in the joints

The geometry of joint, size of brazed surfaces as well as properties of bound materials have a particular effect of the status of stresses being developed in particular in the cermet part of brazed joint.

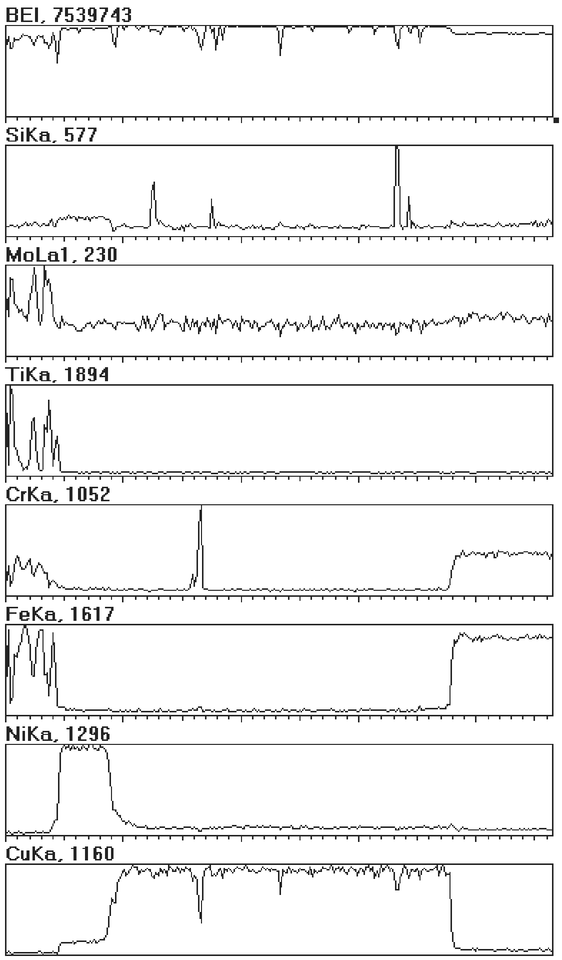

Fig. 7. Distributions of alloying elements in the cross section of brazed joint of of 14-5 PH (X5CrNiMoCuNb14-5) steel - AWS BCu-1 filler metal - Fe-TiC (Ferro-Titanit Nicro 128) sinter

Stresses in joints of 0.05 and 0.15 mm thickness of the WC-Co (ISO K05) and Fe-TiC (FerroTitanit Nicro 128) sinters plates with 65 mm broad 14 -5 PH (X5CrNiMoCuNb14-5) steel plate by Cu based (AWS BCu-1) filler metal were analysed using FEM. 3-D and 2D in selected cross-sections, of the model (Fig. 8) of residual stresses occurring in joints after cooling down from the brazing to room temperature were considered.

Some graphical visualization of the numerical calculations results are presented in Figs. 9-14. It was found that the smallest residual stresess occur in the joint with the thickness of 0.15 mm of Fe-TiC and 14-5 PH steel in the outer part of the model. The larges residual stresess occur in the joint with the thickness of 0.05 mm of WC-Co sinters and 14-5 PH steel in the central part of the model.

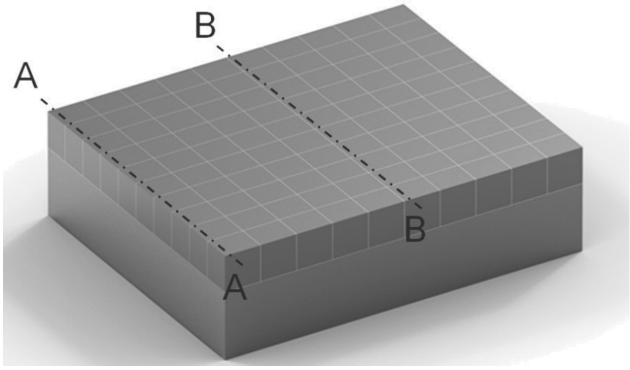

Fig. 8. The three-dimensional model of the braze joint for the FEM analysis, A-A, and B-B cross-sections for two-dimensional analysis

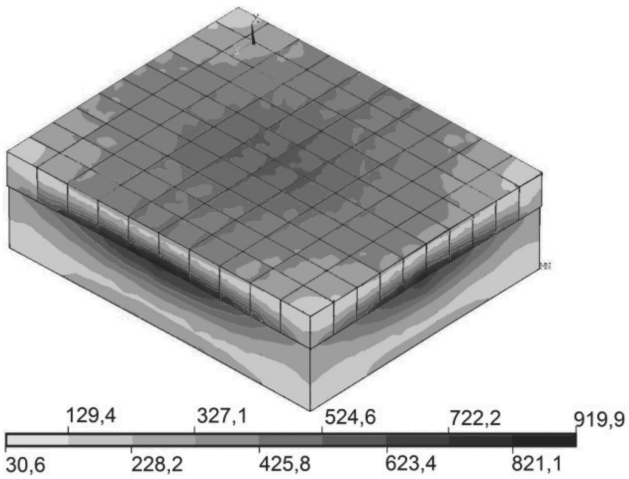

Fig. 9. Three-dimensional model of reduced stress σ_{red} distribution [MPa] in 14-5 PH steel-AWS BCu-1-WC-Co sinter joint of thickness 0.15 mm

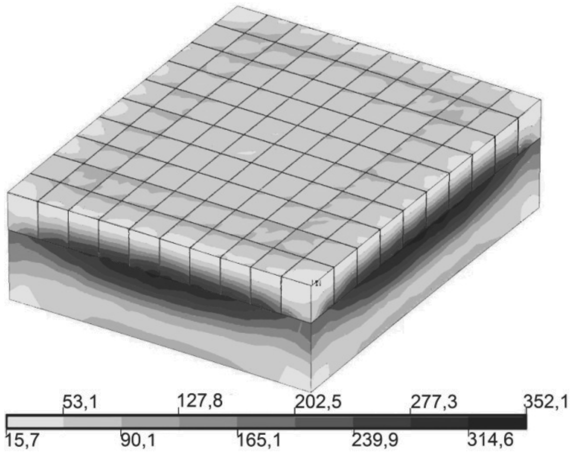

Fig. 10. Three-dimensional model of reduced stress σ_{red} distribution [MPa] in 14-5 PH steel-AWS BCu-1-Fe-TiC sinter joint of thickness 0.15 mm

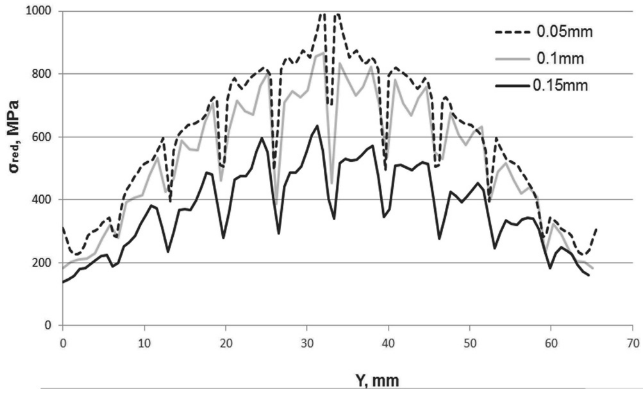

Fig. 11. Two-dimensional reduced stress σ_{red} distribution, [MPa] in 14-5 PH steel - AWS BCu-1- WC-Co sinter joint with different joint thickness: 0.05; 0.1; 0.15 mm, A-A cross-section

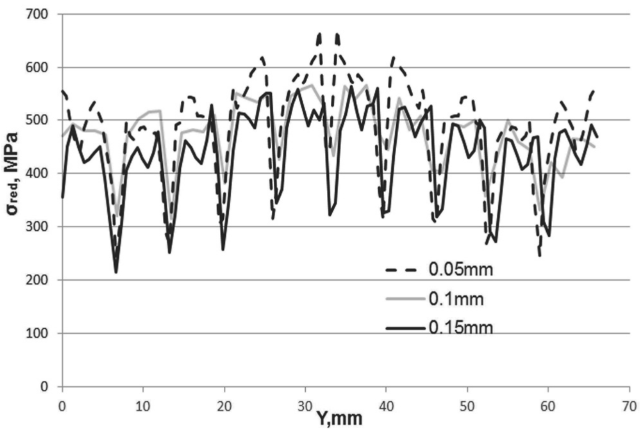

Fig. 12. Two-dimensional reduced stress σ_{red} distribution, [MPa] in 14-5 PH steel-AWS BCu-1-WC-Co sinter joint with different joint thickness: 0.05; 0.1; 0.15 mm, B-B cross-section

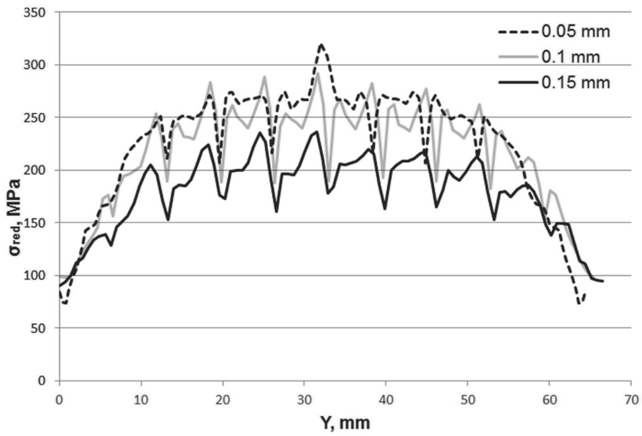

Fig. 13. Two-dimensional reduced stress σ_{red} distribution, [MPa] in 14-5 PH steel-AWS BCu-1-Fe-TiC sinter joint with different joint thickness: 0.05; 0.1; 0.15 mm, A-A cross-section

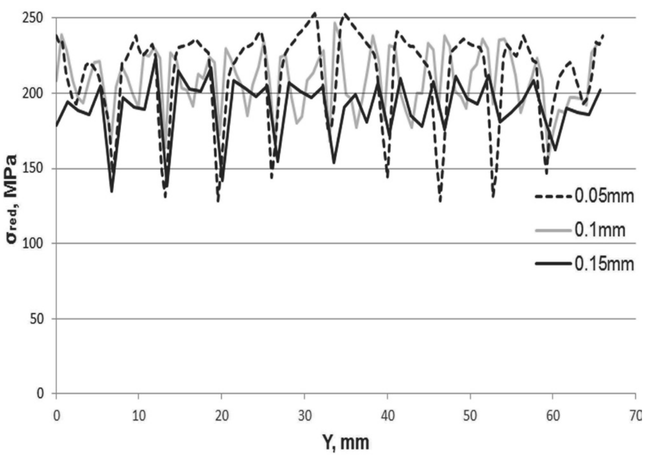

Fig. 14. Two-dimensional reduced stress σ_{red} distribution, [MPa] in 14-5 PH steel-AWS BCu-1-Fe-TiC sinter joint with different joint thickness: 0.05; 0.1; 0.15 mm, B - B cross-section

4. Conclusions

Microstructure of the joints is affected by a range of factors:

- brazing conditions, character of reaction on the separation surface of liquid and solid phases, size of brazing gap,
- properties of bound materials and width of brazing gap affecting internal stressesdimensions of plates; large size plates are a cause of higher internal stresses in brazed joints.

The tested braze joints indicate a composed laminar microstructure with a zone of cooper base solid solution with cermets and steel constitutions and diffusion transient zones in the steel-filler metal and filler metal-cermet-steel boundaries. Basic factors reducing stresses which may occur during vacuum brazing of stainless steels and cermets are: high thickness of the joint, and high volume fraction of metal matrix in the cermets plates. The higher volume fraction of a matrix in a composites in Fe-TiC composites and their higher ductility, than in WC - Co sinters result in lower residual stresses in the joints with Fe-TiC sinters. Higher joint thickness and in result higher joint deformability cause decreasing of residual stresses. On the other hand high thickness of the joint result in its lower shear strength R_t and tensile strength R_m.

Acknowledgements

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