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Microstructure and characteristics of high dimension brazed joints of cermets and steel

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Properties

ABSTRACT

Purpose: In the article a state of the question concerning stresses in brazing joints of different physical and mechanical properties was appraised as well as possibility of their decrease due to use of different techniques from technological experiments to numerical methods. Evaluation of microstructure and mechanical properties of large dimensional vacuum brazed joints of WC – Co and Ferro Titanit Nicro 128 sinters and precipitation hardened stainless steel of 14 –5 PH (X5CrNiMoCuNb14-5) using copper and silver – copper as the brazing filler metal.
Design/methodology/approach: Microscopic examinations with the use of scanning electron microscope (SEM) were performed to establish microstructure and diffusion influences on creation of intermetallic phases in the joint. Shear strength Rt and tensile strength Rm of the joints have been defined. It have been state, that the basic factors decreasing quality of the joint, which can occur during vacuum brazing of the WC - Co ISO K05 sinter – Cu or Ag - Cu brazing filler metal – 14 -5 PH steel joints are diffusive processes leading to exchange of the cermets and brazing filler metal elements and creation of intermetallic in the joint. It can have an unfavourable influence on ductility and quality of the joint.
Findings: Results of numerical calculations of two-dimensional models of brazed joints for different sizes of surfaces brazed at a constant width of solder gap are presented. Particular attention was paid to stresses occurring in joints of large brazing surfaces.
Results of the investigate proved that joints microstructure and mechanical properties depend on filler and parent materials, diffusion process during brazing, leading to exchange of the cermets components and filler metal as well as joint geometry (mainly gap thickness).
Practical implications: The results have been applied in surfaces are used in large dimension spinning nozzles of a die for polyethylene granulation, in that considerable strength, ductility and friction resistance of them are required.
Originality/value: The effect of joint geometry (soldering clearance size, inter-plate distance, plate geometric parameters) on its microstructure and the status of stresses and deformations as well as on the process of plate cracking has been determined.
Keywords: Brazing; Cermets; Mechanical properties; Microstructure; Stresses

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1. Introduction

Possibility of the optimum use of cermets qualities, e.g. high hardness, resistance to abrasion wear, chemical and thermal resistance when reducing their basic flaw which is small ductility, offers a design of machine and tool parts aiming at elimination or significant limitation of tensile stresses being present in them. This requires proper supporting of an element with small ductility, most frequently as a result of connecting it with an element made of steel which is characterised by acceptable shear strength, yield point, impact strength, relative strain and corrosion resistance. Such a joint has to fulfil also a number of geometric conditions making construction integrity and possibility of the effective compensation of stresses induced by a different value of coefficients of thermal expansion for the elements being joined possible. Brazed joints belong to those ones which can match the aforesaid requirements, while broad possibilities of controlling the joint properties in consequence of selecting a filler metal, joint geometry, soldering method and parameters allow joining materials which differ very much in their properties.

An important step in development of hard soldering is case studies referring to physico-chemical and metallurgical foundations of this process, being recently a subject of scientific publications. However, a number of aspects of the soldering process, in particular of materials of different chemical composition and properties, still require further research works [1-4].

The effect of joint geometry (soldering clearance size, inter-plate distance, plate geometric parameters) on its microstructure and the status of stresses and deformations as well as on the process of plate cracking has not been explicitly determined. Despite practical applications, interpretation of the original causes of cracking, in particular in the soldering of cermets and steel on large surfaces, is incomplete [5-10].

2. Abrasion-resistant layers of cermet plates brazed on steel surface

According to the most recent concepts, a surface resistant to abrasion of large machine elements, e.g. die cutting elements in polymer plastics granulators as well as elements of hard raw material grinding mills and mixers, is being made as a lining from cemented carbides brazed to a body in order to increase their wear resistance (Figs. 1-3) [11, 13].

Plates produced in leading powder metallurgy plants assure high and repetitive quality of such a layer. Owing to a small size of plates as well as their welding with a body with a plastic solder, minimisation of stresses in a layer made this way is possible. The thickness of plates allows multiple sharpening of the cutting surface through grinding.

The strength and the plasticity of seal show a strong dependency on the size of soldering clearance with the assumed composition of filler metal. Complexity of the problems of steel-cermet welding quality is particularly clear in case of large size machine and tool elements covered with abrasion-resistant cemented carbide or carbide-steel plates.

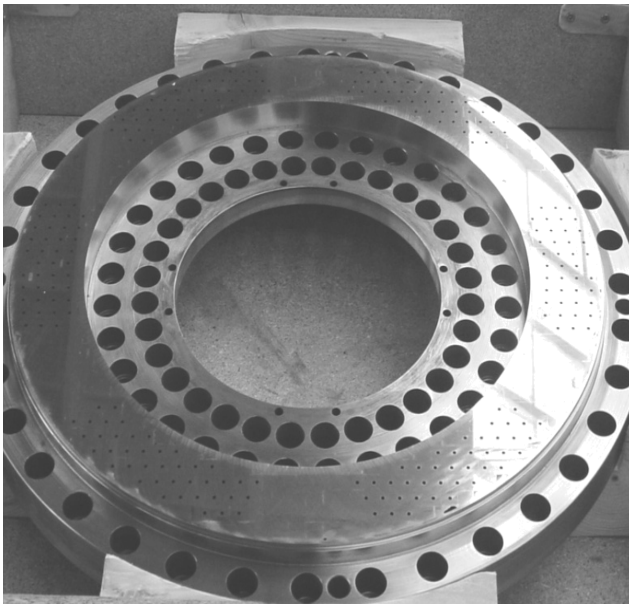

Fig. 1. The view of spinneret for polypropylene granulation with wear resistance layer about hig dimensional surfac, coated cermet plates

Fig. 2. View 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 base

Reports referring to the effect of construction of brazed joint elements on their properties are focused on small size joints. There are no generalised criteria enabling determination of the optimum geometry of joint, including the size of soldering clearance. Problems of the effect of joint surface size on its characteristics of microstructure and properties are not being considered at all.

A perspective method for increasing the wear resistance of large size surfaces proved to be formation of a mosaic lining on them from submicron cemented carbide and carbide-steel plates brazed to a device's body.

Making the cutting surface of a tool or a surface resistant to abrasion on machine elements made of welded materials of different structure and properties poses a threat of cracking of cermet plates. In particular, this takes place in case of soldering on large surfaces of cermets and corrosion-resistant steels with high mechanical properties. Among causes of the cracking of cermet plates, apart from the aforesaid ones, stresses and deformations in a joint induced by mechanical and thermal loads are of significant importance [11-13].

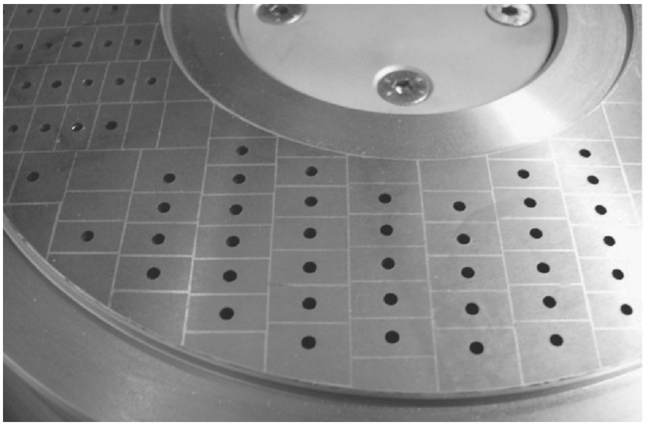

Fig. 3. View of a spinning nozzle used for polyethylene granulation of with the abrasion-resisting layer of a large size surface covered with plates of cermets brazeded to the base

In that case, thermal stresses resulting from heating and cooling when one of the joint elements is being characterised by small value of coefficient K_{Ic}, as it is in case of cermets, are of particular importance. The coefficient of linear expansion for these materials are usually much smaller than those of metal alloys, which can be a cause for development of local tensile stresses of considerable values in a material with smaller expansion.

High level of internal tensile stresses related to high embrittlement of materials will cause their cracking which, under certain conditions, will limit a possibility of their welding. A threat of crack development in sintered materials increases within a temperature range of 750 to 700°C in connection with a possibility of steel phase transitions and volume changes accompanying them [3, 11, 13]. In general, no cracking is observed in the metallic part of joint owing to a possibility of plastic deformation of this area. Cracking develops in the cermets part of joint (Fig. 4).

Many researchers show that it is possible to avoid cracks or significantly limit the occurrence of cracks through appropriate selection of filler metal and soldering clearance and application of compensation meshes and post-soldering heat treatments. However, it is possible to find examples of brazed joints of carbides sintered with steel where bad matching of the shape of carbide plate and steel element leads to local stress concentration and steel element cracking.

At the phase of constructing brazed joints, there is a greatest possibility to shape their quality, among others through searching for the optimum construction of joint and selection of materials. A desired result can be attained under the condition of precise determination of the status of joint stresses.

During operation, local plastic strains can show in a brazed joint, as well as cracks in its brittle elements, the more probably the larger is difference between the size of actual stresses and of those calculated in the process of designing. At the same time, due to changes in structure, physical and mechanical properties of the materials from which joint elements are made, are being changed, i.e. the yield point, tensile strength, hardness, coefficient of elasticity, damping coefficient, and thermal conductivity.

As a result of these transformation, a joint can have other properties than at the stage of designing, which cam also induce further lowering of its ductility. Problems of the transformations of structure, properties and in particular of stresses and deformations in layers resistant to abrasion with large size surfaces covered with cermet plates brazed to precipitation hardened stainless steels, despite being a subject of practical applications, have not been analysed at the basic level yet.

a) b)

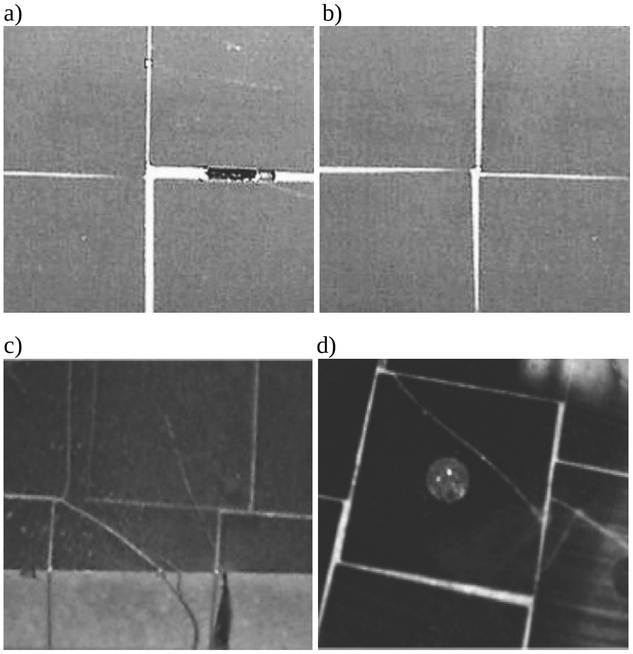

Fig. 4. Examples of defect of the abrasion-resisting layer covered with plates of cermets brazed to the base, a – non-uniform and insufficient thickness of the filler metal between carbides, b – areas unfilled with the filler metal, c and d – cracks of cermets plates as a result of too small seal thickness

In particular, a problem of the effect of joint geometry, i.e. soldering clearance size, dimensions and mechanical properties of cermet plates, inter-plate distance and the size of surface covered with plates, on joint structure and properties as well as joint stresses and deformations requires a detailed description. The lack of detailed data in this area is a reason of many defects formed in the analysed layers. Problems of the effect of joint surface size on its microstructure and properties is of particular importance in brazed joints of cermets with small ductility and large surface precipitation hardened stainless steels have been examined to a small extent, while having larger and larger importance due to practical application [11 - 14].

3. Brazing tests

For brazing tests, precipitation hardened stainless steel X5CrNiMoCuNb14-5 was used, being characterised by a good corrosion resistance, high mechanical properties and heat treatment parameters similar to soldering parameters. As a grade of cermet plates with a small fraction of the metallic phase, high degree of concentration, high hardness and abrasion resistance, G30 and HF10 cemented carbide and Ferro-Titanit Nicro 128 carbide-steel plates compacted isostatically were used (Fig. 5), (Tab. 1-2). As the filler metal, the following solders were used: Ag401 in preliminary tests and a copper solder Cu 106 and a nickel filler metal BNi2 in the main experiment (Tab. 3-5).

Table 1.
Chemical composition and properties of cermets G30 and HF10

Grade of cermet	Chemical composition %			Density g/cm^3	Hardness HV30 kg/mm^2	Bending strength Rg N/mm^2
	Co	WC	TaC/NbC			
HF10	10	88.5	1.5	14.45	1600	≥3500
G30	15	85	-	14.0	1150	2400

Table 2.
Chemical composition and mechanical properties of cermets Ferro Titanit Nicro 128 [acc. Edelstahl Witten Krefeld Gmbh]

Chemical composition % % wag. (bal)						
Reinforcement	Matrix					
TiC	C	Fe	Cr	Mo	Co	Ni
30.0	–	Bal	9	5	9	4

Physical-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

Table 3.
Chemical composition solder Cu106 and Ag401, %

CU 106			AG 401	
Cu	Ag	Another	Ag	Cu
6.0 - 8.0	0.75 - 3.50	4.0 - 5.0	71 - 73	27 - 29

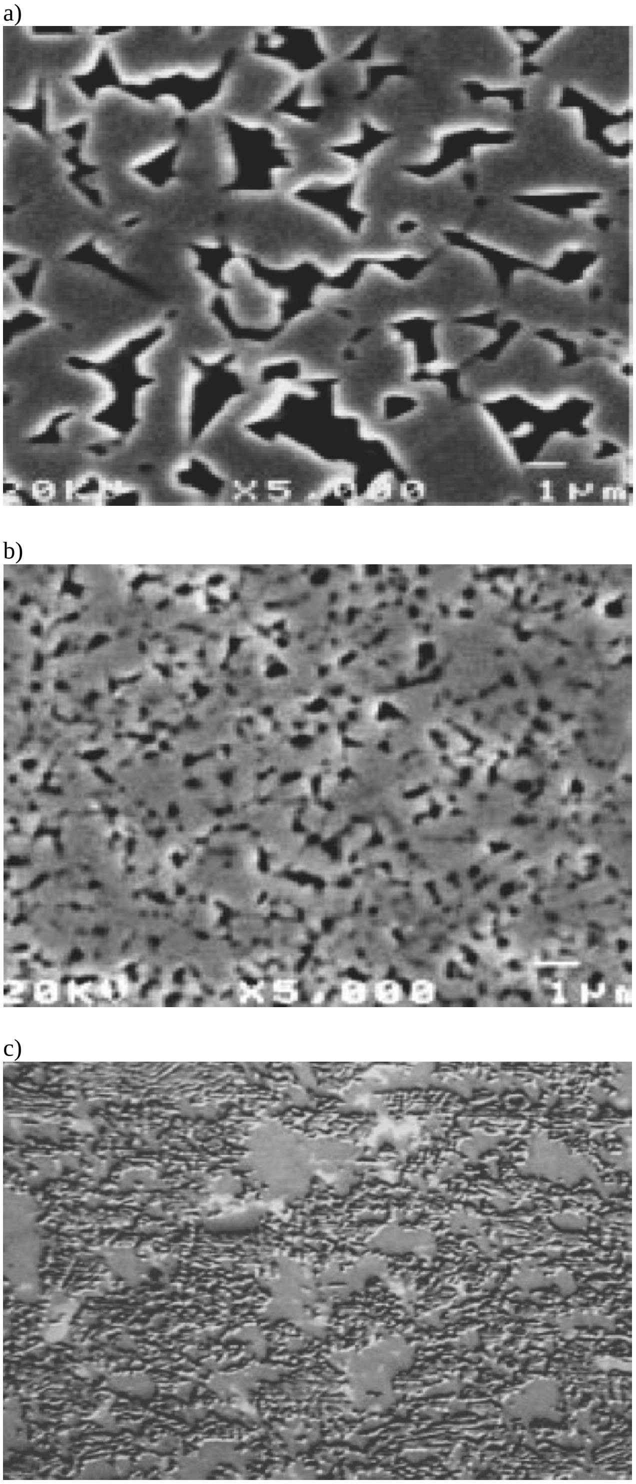

Fig. 5. Microstructure of cermets used of research: a) cermet G30 coarse-grained WC in cobalt matrix, b) submicro cermet HF10, fine-grained WC in cobalt matrix, c) cermet Ferro Titanit Nicro 128 TiC in highly alloyed ferrite matrix

Table 4.
Chemical composition filler metal BNi2, %

Cr	B	Si	Fe	C	Ni
6.0 - 8.0	0.75 - 3.50	4.0 - 5.0	2.5 - 3.5	max. 0.06	reszta
solidus: 970 ^{o}C, liquidus: 1000 ^{o}C, brazing temperature: 1000 - 1075 ^{o}C					

The X5CrNiMoCuNb14-5 steel has high mechanical properties at a room temperature and negative temperatures. The corrosion resistance of X5CrNiMoCuNb14-5 steel is similar to that of classic martensitic stainless steels (Tab. 6). Heat treatment parameters of the X5CrNiMoCuNb14-5 steel are similar to soldering parameters of selected cemented carbides and carbide-steels (Tables 1- 6).

Table 5.
Brazed parameters for solder Cu 106 and BNi2

Speed of heating to brazing temperature ^{o}C/h	Isothermal stop in heating ^{o}C/h	Brazing temperature ^{o}C
100	1010/0.5	1070 - 1100
Brazing time min.	Atmosphere	Speed of cooling from brazing temperature ^{o}C/ godz.
10	Vacuum 10^{-3} Pa	to 850 ^{o}C / 0.5h stop isothermal 0.5 h and very speed cooling at nitrogen atmosphere

The carbide phase in carbide-steels is titanium carbides TiC, practically insoluble in the steel matrix during heat treatment. The volume fraction of matrix in sinter is significantly higher than in cemented carbides and for the most part exceeds 50%. Therefore, carbide-steels are characterised by significantly higher ductility than cemented carbides but at the same time by frequently higher resistance to abrasion wear than tool steels.

Table 6.
Chemical composition and physical-mechanical properties of steel X5CrNiMoCuNb14-5

Chemical composition %											
Ni	Cr	Mn	Si	Cu	Mo	Nb	Ta	C	P	S	Fe
5.0 – 5.8	13.2 – 14.7	0.5 – 1.0	0.6	1.2 – 2.0	1.2 – 2.0	0.2 – 0.7	1.7	0.07	0.04	0.03	Bal

Physical-mechanical properties					
Tensile strength Rm N/mm^2	Yield stress $R_{0,2}$ N/mm^2	Elongation A_5 % min.	Hardness HRC	λ W/mK	α $^{10-6}$ K-1
647-1470	539-1093	10-23	29-40	17.165	0.771

Preliminary tests of the process of X5CrNiMoCuNb14-5 steel soldering with cemented carbides G30 and HF10 showed that vacuum soldering of large machine elements made of stainless steels with cermets makes a number of problems which can be less important during soldering with other methods. On the other hand, no possibility of using fluxing agents during soldering induces a necessity of replacing them with vacuum reduction processes, which significantly reduces freedom of soldering temperature selection. These problems are first of all caused by significantly longer time of vacuum soldering when compared with other soldering methods, lack of fluxing agents and necessity of applying volume heating. Long soldering time is a cause of significant contribution of diffusion processes during welding, which frequently lower the quality of seal in result, for example, of:

- formation of brittle seal intermetallic phases or seal-bound material separation surfaces,
- diffusion of e from bound materials to solder inducing a change in solder chemical composition, increase of soldering temperature and seal brittleness,
- replacement of the components of bound materials with those of solder, e.g. of cobalt in cemented carbides with copper from filler metal, which weakens the efficiency of cobalt bonding of carbides, and
- vacuum evaporation processes inducing a change in the solder composition and soldering temperature.

In next examination stages, a number of phenomena unfavourable by reason of the effect of process and the quality of seal was observed in joints, e.g.:

- raising of plates during soldering as a result of hydrostatic force action,
- uneven and frequently insufficient thickness of filler metal between carbides in the horizontal section and between steel and cemented carbides in the vertical section, being one of the causes of carbide cracking, because of insufficient relaxation of internal stresses and those resulting from differences in thermal expansion coefficients of steel and cemented carbides,
- formation of areas with no joint or uneven joint,
- unfavourable effects of diffusion processes between solder components, cemented carbides and steel leading to the formation of solid solutions with significant hardness and brittle intermetallic phases, and cracks in cemented carbides.

4. Joint microstructure

The X5CrNiMoCuNb14-5 steel – Cu 106 – G30 and the X5CrNiMoCuNb14-5 steel – BNi2 – Ferro-Titanit Nicro 128 as well as the X5CrNiMoCuNb14-5 steel – Ag401 – HF10 joints have a typical eutectic structure with a zone of intermetallic compounds in the separation plane of steel-filler metal and filler metal-carbide-steel seal matrix (Figs. 6 – 11).

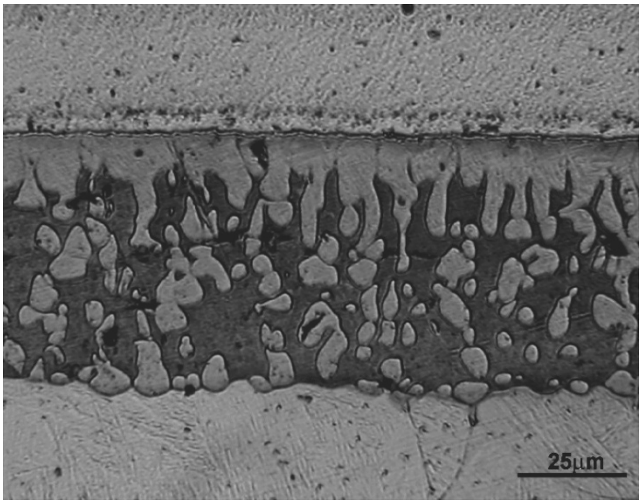

Fig. 6. Brazed joint of X5CrNiMoCuNb14-5 – Cu 106 – G30

Fig. 7. Microstructure of brazed joint of X5CrNiMoCuNb14-5 – BNi2 – Ferro Titanit Nicro 128

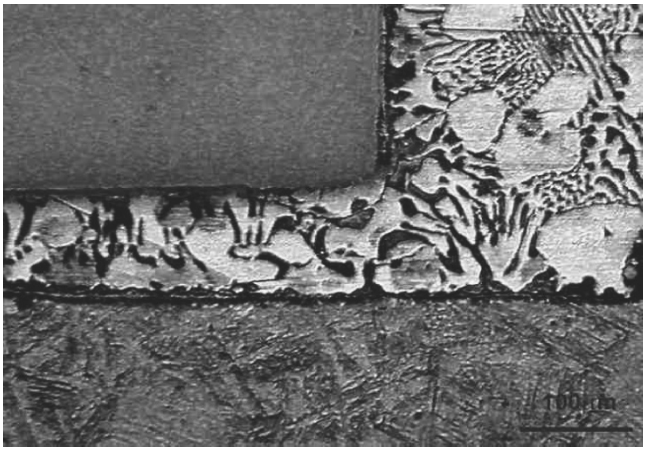

Fig. 8. Brazed joint of X5CrNiMoCuNb14-5 – Ag401 – HF10

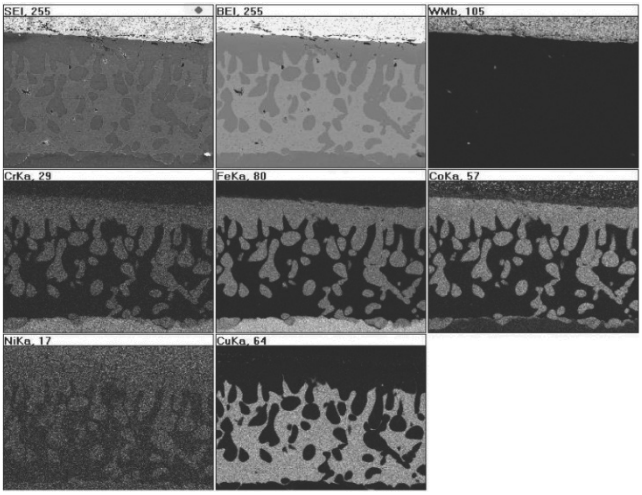

Fig. 9. Brazed joint of X5CrNiMoCuNb14-5 – Cu 106 – G30, chemical distributions of alloying elements

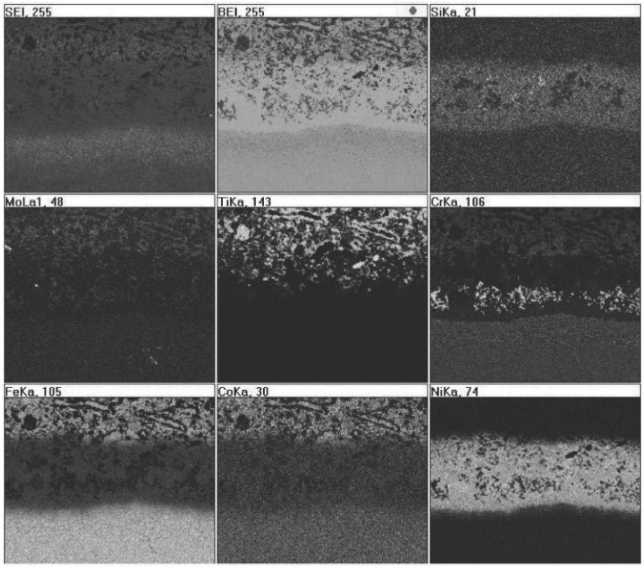

Fig. 10. Brazed joint of X5CrNiMoCuNb14-5 – BNi2 – Ferro Titanit Nicro 128, chemical distributions of alloying elements

The zones of intermetallic compounds differ clearly in their chemical composition from the seal matrix. The produced seals have a zonal structure illustrated in Figures 12, 13 and 14. There are reactive zones in the carbide-steel-filler metal separation plane, being characterised by different chemical composition than the seal matrix.

The reactive zone is rich in titanium, molybdenum and iron from the carbide-steel side, while a silicon-rich zone is in the seal axis [central line] and an iron- and nickel-rich one in filler metal-steel separation plane.

In the nickel- and iron-rich filler metal matrix, there are chromium-rich intermetallic phases containing in total several percent of nickel, iron and molybdenum

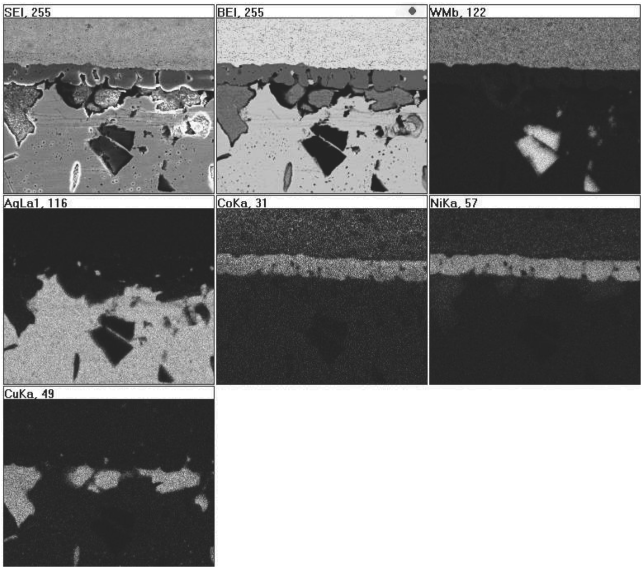

Fig. 11. Brazed joint of X5CrNiMoCuNb14-5 – Ag401 – HF10, chemical distributions of alloying elements

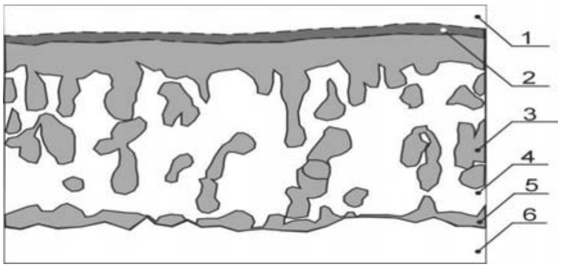

Fig. 12. Scheme of structure brazed joints Cu 106-G30-steel X5CrNiMoCuNb14-5, 1-cermet G30, 2-transient zone contained cermet and filler metal constituents, 3-solder - intermetallic phase from phase equilibrium system Fe-Co, Fe diffusion to steel direction, 4-solder, Cu based solid solution, 5 – transient zone contained steel and filler metal constituents, 6 - steel X5CrNiMoCuNb14-5 base

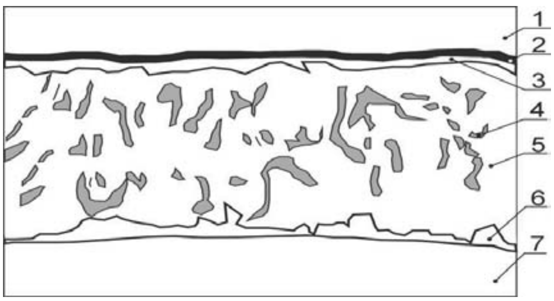

Fig. 13. Scheme of structure brazed joints FerroTitanit Nicro 128 –steel brazed AWS BNi2 filler metal: 1-cermet FerroTitanit Nicro 128, 2- Ni diffusion barrier, 3- transient zone contained cermet and filler metal constituents, 4- intermetallic phase Cr rich, 5- Cr-Fe and Ni solid solution, 6- diffusion zone Cr, Fe and Ni rich, 7- base -steel X5CrNiMoCuNb14-5

5. Stresses in brazed 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 ceramic part of brazed joint.

Preliminary tests of brazed joints show effect, among others, of the geometry of joint and materials, of which this joint has been made (Fig. 15).

In case of the examined joints, a simultaneous change of the seal thickness from 0.05 mm to 0.15 mm, a change of the yield point of seal from 180 MPa to 70 MPa and a replacement of G30 carbide plates with Ferro-Titanit Nikro 128 cermet plates gives over a fivefold reduction of the maximum values of tensile stresses σ_y in brazed plates (Fig. 16).

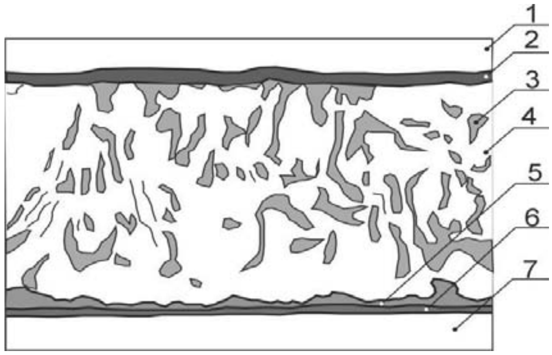

Fig. 14. Scheme of structure brazed joints HF10-AG401 -steel: 1- cermet HF10, 2- transient zone contained cermet and filler metal constituents, 3-solder-intermetallic phase Cu, Ni and Ag, 4 - solder - Ag-Cu solid solution,5 - transient zone contained steel and filler metal constituents , 6- Ni diffusion barrier, 7 – steel

The surface of brazed elements is important for the soldering process and the joints with good properties being obtained, but first of all the size of cermet plates. In the analysed model, ten 6.5 mm broad plates were replaced with one 65 mm broad carbide plate. For such a construction form of the joint model, calculations were made. On Figure 16, distribution curves for normal stress σ_y in carbides at their external surfaces are showed.

When comparing the distribution of σ_y in the plates of carbide models with one or ten plates, it can be seen that plates with arbitrarily large dimensions should not be used in brazed joints due to the level of internal stresses. In case of the first model (plate width 65 mm, curve b), stress σ_y exceeded a dangerous value (R_{mw}=300 MPa).

The importance of problems connected with internal stresses appearing in joints with large soldering surfaces during soldering (Fig. 17, curve b) is particularly large when compared to that of problems referring to joints with small soldering surfaces (Figs. 17 c, d and e).

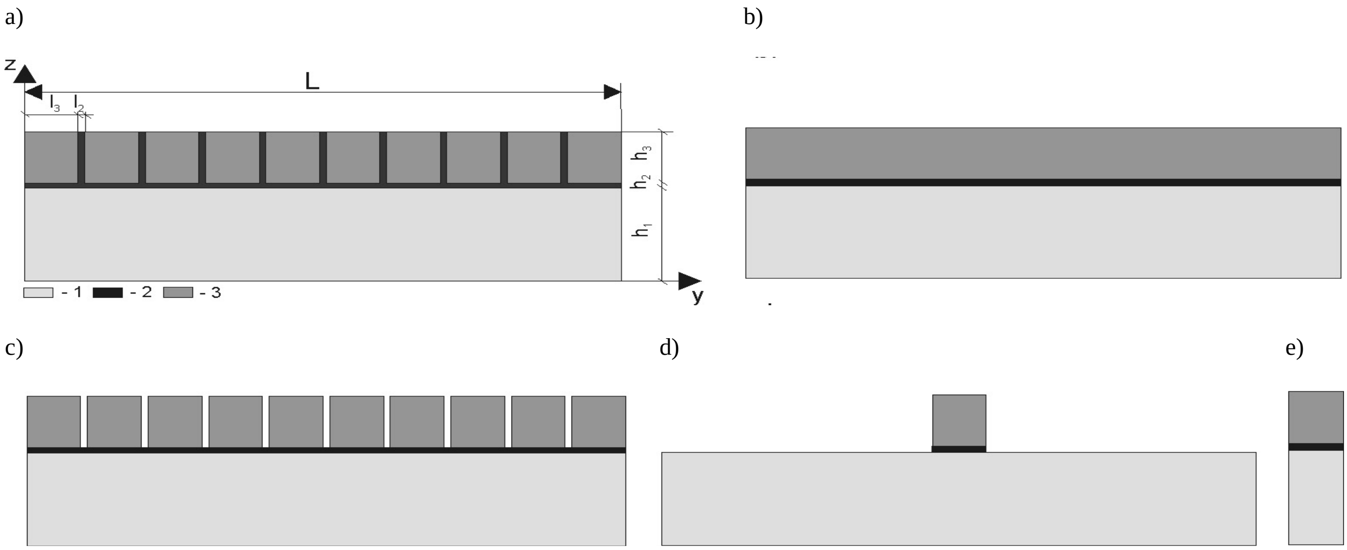

Fig. 15. Two-dimensional physical models brazed joint: 1- steel, 2- filler metal, 3- cermet (L=66,35mm; h_1=15mm; h_2=0,15 mm; h_3=8,0 mm; l_2=0,15 mm; l_3 = 6,5 mm); ten cermet plates, b) one cermet tip about dimension L, c) ten cermet plates, no vertical gaps, d and e) one cermet plate about dimensional l_3 for small and large steel surface

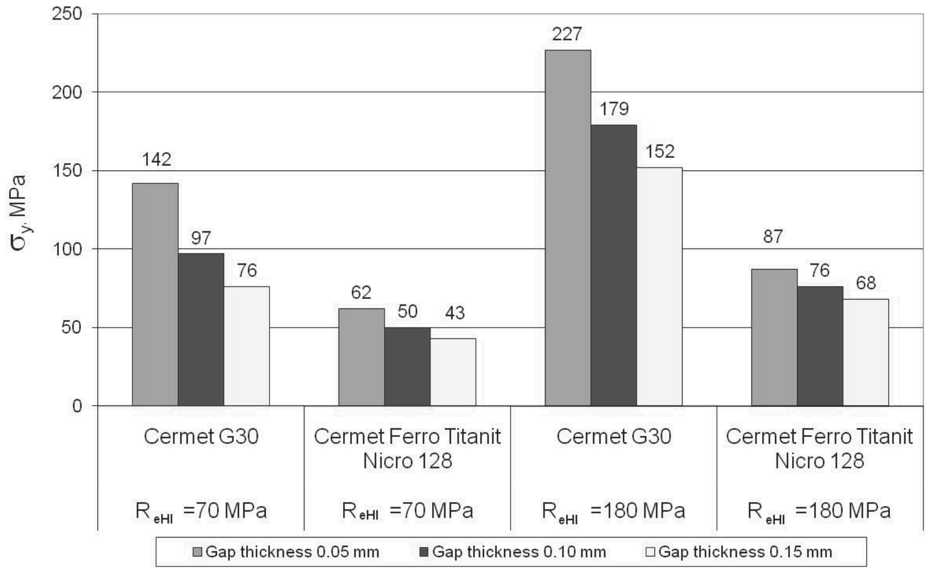

Fig. 16. Comparison of maximum value stresses σ_y for model of different gap thickness, materials and yield stresses, model as on 14a

Table 7.
Results of the brazed joints static tension test and sharing test

Means of machining, and Ra	Gap width	X5CrNiMoCuNb14-5 – BNi2 – Ferro titanit Nicro 128		X5CrNiMoCuNb14-5 – Cu 106 – G30	
	mm	Average R_t N/mm^2	Average R_m N/mm^2	Average R_t N/mm^2	Average R_m N/mm^2
Milling, Ra = 4.08	0.08	211	325	193	270
Grinding, Ra = 1.82	0.07	172	296	166	243
Polishing, Ra = 0.08	0.06	156	278	138	210

6. Joint mechanical properties

Due to the fact that sample distancing was not applied, the size of soldering clearance being decisive for the seal strength depended on the base roughness and the pressure exerted on plates (Tab. 7). The vacuum carbide-steel and precipitation hardened stainless steel soldering technology developed was verified in practice.

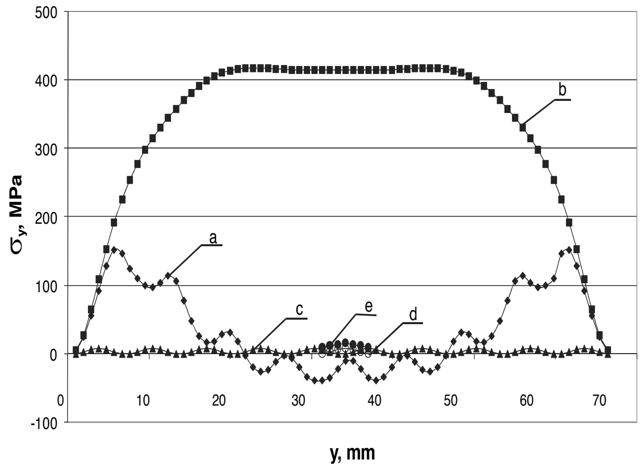

Fig. 17. Normal stresses σ_y in cermets G30 for five models brazed joints, different size of brazing surfaces y: a) 66,35mm, b) 66,35 mm, c) 66,35 mm, d) 6,5 mm, e) 6,5 mm

7. Conclusions

In order to ensure a high quality of joint on large surfaces, it is necessary to:

- use plates with possibly large fraction of metallic phase,
- carry out selection of cemented carbide plates with respect to surface defects, homogeneity of plate colour, and the presence of cracks and chippings,
- ensure a seal thickness of 0.2-0.4 mm,
- ensure an inter-plate distance of 0.2-0.4 mm,
- use nickel or cobalt layers that increase wettability of plates,
- clean thoroughly and degrease the elements intended for soldering,
- reduce carefully oxides on the surfaces intended for soldering through vacuum annealing,
- centre individually cemented carbide plates,
- solder on precisely levelled base and load brazed surfaces,
- use possibly short soldering times and low soldering temperatures,
- use filler metals with a possibly low soldering temperatures for soldering,
- warm up slowly to soldering temperature with isothermal plateaus,
- cool down slowly after soldering with isothermal plateaus,
- fill in eventual discontinuities between plates with solder with lower melting temperature.
- Basic factors reducing the seal quality which may occur during vacuum soldering of stainless steels and cermets are:
- diffusion processes leading to exchange of the components of cermets and filler metal,
- small wettability of cermets,
- heterogeneity of the chemical composition, structure and density of available cermets,
- proper selection and optimisation of soldering parameters aiming at reduction of temperature gradients and limitation of diffusion processes as well as application of coatings
- which increase the wettability of cermets with a filler metal significantly eliminates the factors reducing the seal quality.

An important issue in designing the technology of steel and cemented carbide soldering on large surfaces is problems of the quality of this surface being reduced to:

- assurance of the assumed seal strength and ductility,
- even distribution of plates on the whole surface, frequently of large size,
- constant and internal and thermal stresses-ensuring thickness on all plates,
- thermal load size during soldering process due to which internal stresses develop that can cause local cracks in the ceramic part of joint,
- integrity of the steel-plate and the plate-plate joint, and
- preservation of the properties of plates which they had before soldering.
- The quality of seal is mainly decided by the following factors:
- wettability with melted filler metal of the bound surfaces under soldering conditions, character of reaction on the separation surface of liquid and solid phases, size of soldering clearance in the steel-plate system affecting, among others, joint internal stresses; increase in the width of soldering clearance decreases internal stresses in brazed carbide-cermet plates but at the same time decrease the shear strength of seal,
- properties of bound materials and width of soldering clearance affecting internal stresses, which first of all depends on the yield point of seal and grows together with a decrease in its value,
- dimensions of plates; large size plates are a cause of higher internal stresses in brazed joints.

Acknowledgements

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