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Brazing of 14-5 PH steel and WC-Co sinterson considerable dimension surfaces

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ABSTRACT

Purpose: of this paper is study of structure properties of considerable surfaces vacuum brazed joints of WC-Co sinters and precipitation hardened stainless steel of 14-5 PH using copper and silver-copper as the brazing filler metal.

Design/methodology/approach: the joints are used in large dimension spinning nozzles of a die for polyethylene granulation, in that considerable strength and ductility of the joints are required. Structure and mechanical properties of joints have been described. Shear strength Rt and tensile strength Rm of the joints have been defined.

Findings: to 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 elements of cermets and the brazing filler metal and creation of intermetalics in the joint. It can have an unfavourable influence on ductility of sinters and quality of joint. As a result of brazing tests the influence of means and parameters of the brazing on quality of a joint was determined.

Research limitations/implications: as a result of the experiments scheme of the joint structure WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joint and WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH have been described.

Practical implications: as a result of conducted experiments a production of spinning nozzle of a die for polyethylene granulation with a vacuum-brazed with a WC-Co ISO K05 sinters plates cutting surface of large surfaces on precipitation hardened stainless steel 14-5 PH have been worked out and industrial applied.

Originality/value: the basic factors decreasing quality of the joint, which can occur while vacuum brazing of stainless steels and cermets have been determined.

Keywords: Tool materials; Mechanical properties; Metallography; Constructional design; Welding

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Vacuum brazing is particularly profitable for joining machine parts of large dimensions and such that differ as far as the thickness of their walls is concerned or are made of materials characterised by different chemical constitution or mechanical properties [1, 2]. It is most often used for joining machine parts made of age-hardened steel or for steel - ceramics joints. It allows obtaining reproducible and narrow tolerances of dimensions, and the absence of fissures and discontinuity in the joint, as well as its considerable plasticity of the joint [3, 4]. Vacuum brazing has proved to be a very effective method of joining of centrifugal compressors impeller parts and various machine elements providing high quality joint as for mechanical strength, chemical resistance and dimensional accuracy are concerned.

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The contemporary brazed joints have to fill more and more sharper exploitation requirements related to durability, reliability, and higher temperature resistance, static and dynamic strength, corrosion resistances, as well as sometimes various electric properties. Problem of vacuum brazing of considerable quantity of sintered carbides plates with a steel matrix on large surfaces occurs during production of cutting surfaces of dies for granulation of polyethylene (Fig. 1 - 3). Vacuum brazed joints of the WC - Co sintered carbides and stainless steel 14- 5 PH for spinning nozzle of a die for polyethylene granulation are ones of the most advanced brazed joints. They operate at temperatures of about 453 K (180^{0}C), under a changing load caused by a polyethylene flow and by spinneret cut head with knives exerting a local variable pressure and variable friction force on the WC - Co sintered carbides surface.

That's why the WC - Co sintered carbides surface is subjected to considerable friction and wear. A used up cutting surface of the spinning nozzle is subjected to an expensive regeneration [5 – 6]. One of the means of increasing of spinning nozzle WC - Co sintered carbides surfaces wear resistance is optimizing of brazed joint geometrical and mechanical parameters [7 – 8]. Problem of stresses and strains in the brazed joint has an essential influence on the joint properties.

Analytical method proposed by theory of elasticity and plasticity, leading to strict solutions, does not always give effective solution of analyzed problem. Appreciative methods, e.g. finite element method are more effective here, as they give results in numerical form, obtained on way of the multiple numerical analysis.

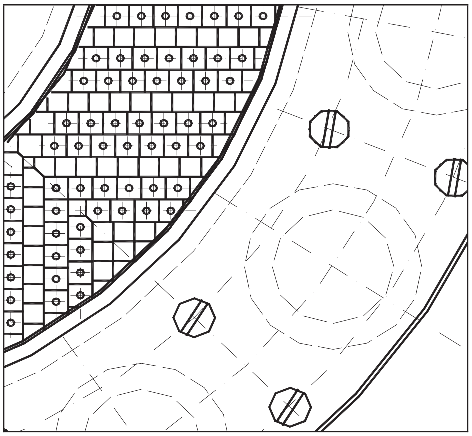


Fig. 1. Scheme of the part of a die for polyethylene granulation with cutting surface made of WC-Co sinters plates brazed to the face of a die body; working plates (with a hole), distanced plates (without a hole)

This method creates possibility of a relatively exact description of geometry, stresses and properties of complex real object [9 – 10]. That's why the finite elements method ensures a considerable results conformity with experimental results. Numerical calculations of tensions and deformations of sintered carbides and 17 - 4 PH steel vacuum brazed joints by means of finite element method of Adina system [11 – 12] have been done in this paper. In the paper there are presented some selected results.

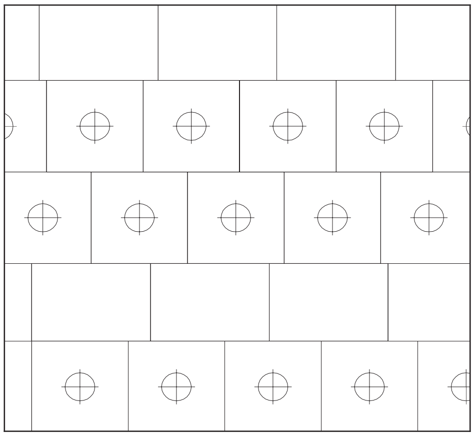


Fig. 2. Scheme of a spinning nozzle of a die for polyethylene granulation surface part with vacuum brazed sintered carbides plates; cutting plates have holes, and plates without holes are used as distancing elements

Complexity of issues of joining quality of steels and cermets is well characterized by issues of a construction and a technology of polyethylene granulator spinnerets made of precipitation hardened stainless steel with a cutting surface made as a mosaic of PM metal matrix composite plates.

Technology, joint structure and properties as well as residual stresses problems of vacuum brazing of considerable number of cermets plates with a steel matrix on large surfaces occur in production of cutting surfaces of dies for granulation of polyethylene.

The polyethylene granulation spinneret is a main unit of a polyethylene granulator (Fig. 1 - 3). Due to a construction, dimensional tolerances, technology and operation conditions the polyethylene granulation spinneret is one of the most complicated and advanced machine units in terms of structure and technology. The polyethylene granulation spinneret consists of systems of polymer transport, heating, shaping, calibration and cutting of a granulated product. They enable homogenization of a resin, increase of polyethylene viscosity, then granulation into elements of a shape, dimensions and tolerances strictly corresponding to international standards. The problem of quality of a produced granulated product remains in a close relation to quality and wear resistance of a cutting surface of the spinneret.

The cutting surface of the spinneret is subjected to wear because of friction with a working together head of cutting knives. Wear of the cutting surface of the spinneret presents as losses of material of a very characteristic, rare in other types of friction, image. There is no, so far, description of elementary phenomena occurring while wear process. Analysis of the wear phenomena of the spinneret has essential meaning for forecasting its durability and optimal, in the aspects of wear resistance, methods of regeneration of its cutting surface. Worn out cutting layer is subjected to an expensive regeneration.

In order to increase wear resistance of the cutting surface of the polyethylene granulator spinneret the surface is covered with a hard cermetallic layer. The layer, most often consisting of wolfram carbide-cobalt, of the cobalt content up to 60%, was traditionally produced using a method of spraying or plasma cladding. But these methods do not assurance required quality and durability of the spinneret and quality of the produced granulated product. Created layers often have technological defects: bad adhesion to the surface and excessive porosity.

Fig. 3. Die for polyethylene granulation with the surface of WC-Co sinters cutting plates brazed to the face die body; 1 – die body, 2 – cover, 3 – cutting surface of WC-Co sinters plates, 4 – cone, 5 – partition of the cone, 6 – insulation roller, 7 – cover of the roller, 8 – insulation ring, 9 – cover of the ring, 10 – brazed joint of a ring with the die body, 11 – ring with brazed WC-Co sinters

A prospective way of increasing of wear resistance of the polyethylene granulator spinneret cutting surface is a creation on it a mosaic lining made from plates of submicron WC-Co sinters brazed to the spinneret body (Fig. 1-2). A construction of the spinneret with the cutting surface made from WC-Co sinters is a subject of many implementations. This solution is the most prospective way of increasing wear resistance of the cutting surface of the spinneret.

The method has following advantages:
- plates produced in specialist powder metallurgy plants have high and repeated quality,
- stresses in the cutting layer are minimized due to little sizes of cutting plates settled in a plastic solder,
- thickness of the cutting plates is usually 3-8 mm, what enables on repeated sharpening of the cutting surface through grinding.

Quality problems of the cutting surface are the essential question of designing of the brazing method of WC-Co sinters and steel on large surfaces come down to:
- assurance of established strength and ductility of the joint,
- even spreading of the cutting plates on whole cutting surface, that has often considerable size,
- thickness of the joint on all plates, which is continuous and ensures relaxation of residual stresses,
- leakproofness of the joint of steel-cutting plate and cutting plate-cutting plate,
- preserving of properties of the cutting plates, which they had before brazing.

Following factors have a major influence on quality of the joint:
- wettablity of joining surfaces by a melted brazing filler metal in conditions of the brazing,
- nature of a reaction on a boundary of liquid and solid phases,
- size of the soldered gap in the joint of steel-cutting plate.

Vacuum brazing of large machines elements made of stainless steels with cermets creates many problems, which can be less essential during brazing using other methods. These problems are caused mainly by a longer time of brazing in vacuum in comparison with the other brazing methods, lack of fluxes and necessity to apply volumetric heating. Long time of vacuum brazing is a reason of a considerable intensity of diffusive processes, which often reduces quality of brazing, resulting in:
- creating of fragile intermetallic phases in the joint or the boundary of the joint-joining material,
- run away of components from joining materials to a brazing filler metal causing an altering of the chemical composition of a brazing filler metal, increase of a brazing temperature and fragility of the joint,
- replacing of components of joining materials and solder, e.g. cobalt in WC-Co sinters with copper from a brazing filler metal, which make weak the efficiency of cobalt bonding of sinters,
- evaporation processes in vacuum producing modifying of a brazing filler metal composition resulting altering of the brazing filler metal melting temperature.

No possibility of fluxes application during the vacuum brazing causes the necessity to substitute their effect on joining course by reduction processes in vacuum. That essentially restricts possibility of a selection of the brazing temperature.

Development of the spinneret construction was a new and complex technological problem and was preceded with many tests aiming optimization of the brazing technology in order to minimization of the mentioned unfavourable phenomena and assurance of acceptable quality of the joint.

The investigation included:
- brazing tests,
- metallographic investigations of the joints,
- investigations of mechanical properties of the joints.

2. Method of the experiment

High strength stainless steel and fine gains WC-Co sinters plates of a small part of metallic phase, high degree of consolidation, high hardness and high wear resistance have been used for the tests. Constructional and technological solution of the spinneret was based on: precipitation hardened stainless steel – 14-5 PH (Tab. 1) and submicron WC-Co sinters plates – hydrostatically pressed WC-Co ISO K05 [13 – 14] (Tab. 2, Fig. 4) joining with steel using a brazing filler metal in the form of foil: copper (Cu), and silver-copper (Ag-Cu) alloy [15] (Tab. 3). Brazing tests were carried out in devices aligning the plates serving as models of the cutting surface of the spinneret of various ways of alignment (Fig. 5). Brazing thermal cycle and brazing parameters are presented on Figure 6 and in Table 4.

Table 1.
Chemical composition of 14-5 PH steel

C	Mn	Si	P	S	Cr	Ni	Mo	Nb	Cu
max 0.07	0.5-1.0	0.6	max 0.04	max 0.03	13.2-14.7	5.0-5.8	1.2-2.0	0.2-0.7	1.2-2.0

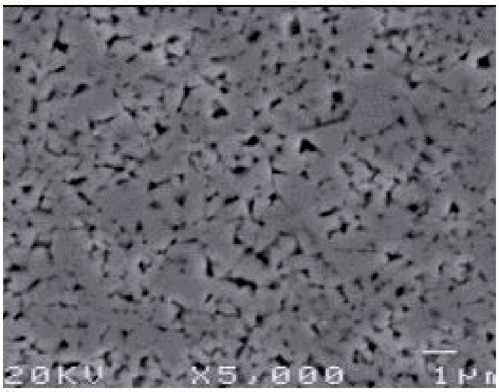


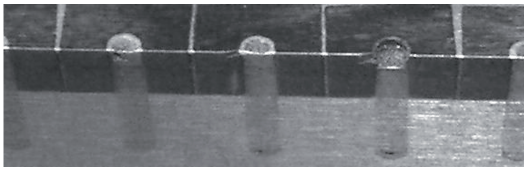
Fig. 4. Microstructure of WC-Co ISO K05 sinter; fine-grained tungsten carbide in a cobalt matrix

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

Chemical composition %			Grain size μm	Bending tensile N/mm^2	Density g/cm^3	Hardness HV
WC	VC	Co				
93.8	0.2	6	<1	1900	14.9	1400

Table 3.
Chemical composition of Cu and Ag-Cu brazing filler metal %

Brazing filler metal	Cu	Ag
Cu	98.8	0.8
Ag-Cu	28.9	71.1

a.

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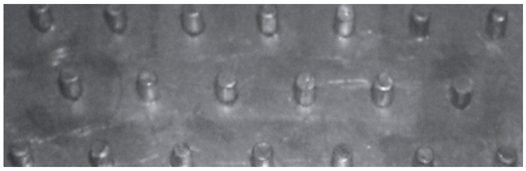

Fig. 5. Examples of the alignment of WC-Co ISO K05 sinters plates; a – fixed on dowels, b – dowels replacement

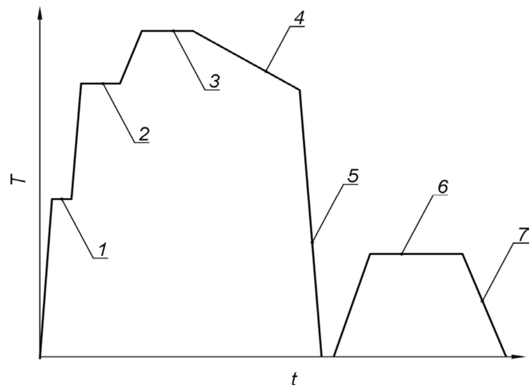

Fig. 6. Scheme of the thermal cycle of vacuum brazing used in the experiment; 1, 2 – isothermal stops while heating, 3 – melting of the brazing filler metal, 4 – slow cooling in vacuum, 5 – fast cooling in nitrogen, 6 – ageing, 7 – cooling after ageing

Table 4.
Parameters of brazing used in the experiment

Brazing filler metal	Isothermal stop while heating up $^oC/h$	Temperature and duration of brazing $^oC/min$	Temperature and duration of aging $^oC/h$
Cu	600 /0.5 1000/0.5	1100/10	450/3
Ag-Cu	750/0.5	800/10	450/3

3. Results

As a result of the tests the influence of the means and parameters of brazing on the joint quality have been determined. Application of the submicron WC-Co ISO K05 sinters should to ensure a better friction resistance but the worse brazeability in vacuum than conventional ones (e.g. ISO K10-K20).

In the first stages of tests a lot of unfavourable phenomena due to an effect of the process and quality of the joints have been noticed, i.e.:

- lifting of plates during the brazing as a result of hydrostatic pressure,
- non-uniform, and often insufficient thickness of a brazing filler metal between plates of sinters, and between steel and plates of sinters being one of the reasons of sinters plates cracks as a result of insufficient relaxation of internal stresses and stresses resulting from differences of thermal expansion coefficients of steel and sinters (Fig. 7),
- cracks of plates of sinters (Fig. 9-10),
- unfavourable effects of diffusive processes between components of a brazing filler metal, sintered carbides and steel leading to production of solid solutions of significant hardness and brittle intermetallic phases (Fig. 11-14).

The diffusive zone of the WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joint in a boundary of sinter–brazing filler metal is rich in cobalt and iron (hardness 420-780 HV), in the joint axis there is a zone rich in copper or silver (hardness 400-800 HV) and in a boundary binding material–steel there is a zone rich in iron, cooper or silver (hardness 150-220 HV). The diffusive zones are characterized by hardness higher than the brazing filler metal matrix and Cu brazing filler metal has higher than the Ag-Cu binding material (Fig 15-16). Correctly completed WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joint is presented on Fig. 17

a.

b.

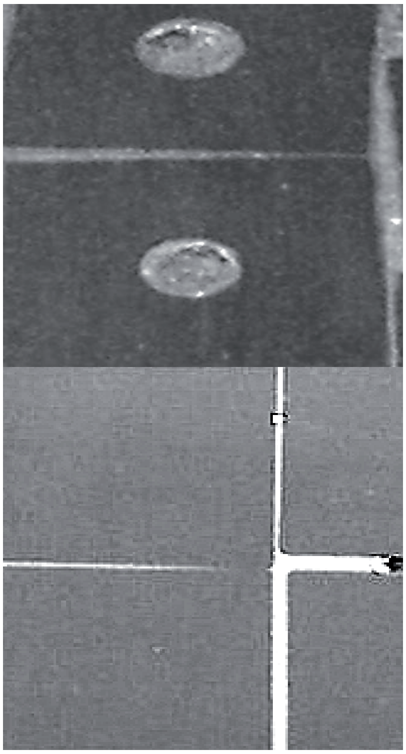

Fig. 7. Vertical sections of a mosaic lining WC-Co ISO K05 sinters plates in the WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joints; a – non-uniform thickness of a binding material between plates, b – not-filled gaps between plates

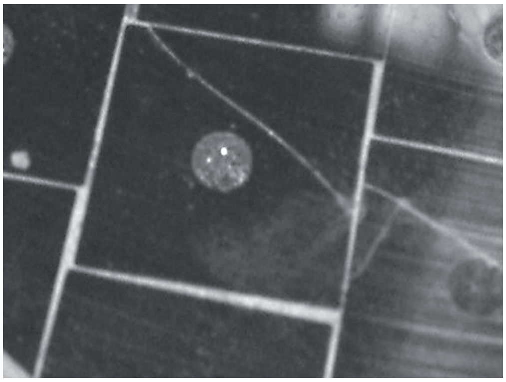

Fig. 8. Cracks of WC-Co ISO K05 sinter plate, being the effect of too small thickness of a WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joint; a view from above

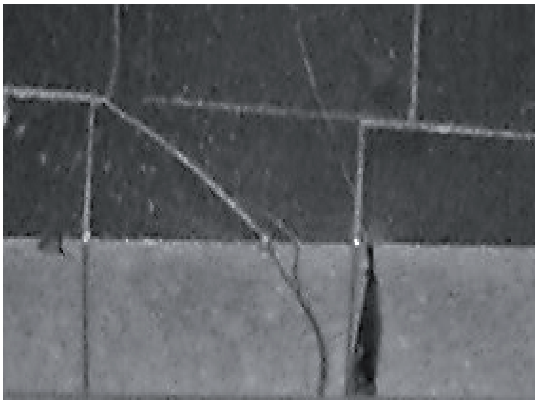

Fig. 9. Cracks of WC-Co ISO K05 sinter plate, being the effect of too small thickness of a WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joint; a side view

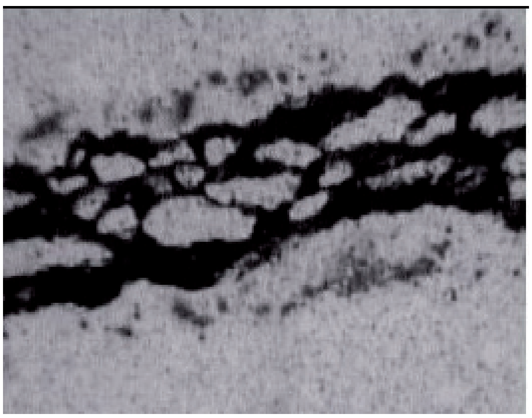

Fig. 10. Cracks of a WC-Co ISO K05 sinter plate, being the effect of weakness of cobalt bonding due to diffusive processes in WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joint, magnification x100

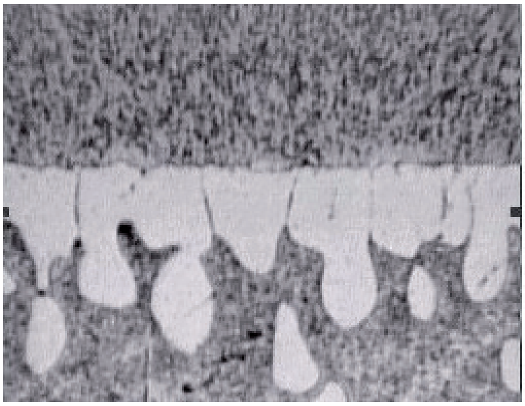

Fig. 11. Microstructure of the joint boundary of WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel, solid solutions and intermetallic phases, magnification x150

Schemes of the joint structure WC-Co ISO K05 sinter – Cu and Ag-Cu brazing filler metal – 14-5 PH steel joint is presented on Fig 18 and 19. The size of the brazed gap, influencing on the joint strength, depends on the surface roughness and pressure exerted on plates (Tab. 5, 6).

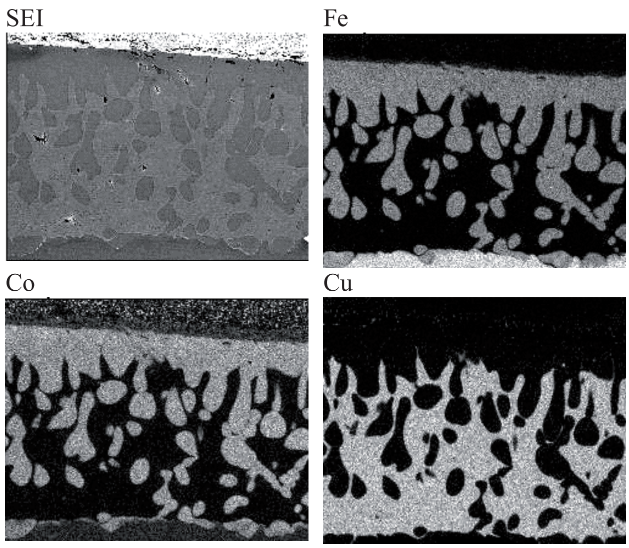

Fig. 12. Microphotography of a micro area of WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joint and surface distribution of main chemical elements, magnification x800

Tensile strength of the vacuum brazed of WC-Co ISO K05 sinter plates and 14-5 PH joints are strongly affected by a size of soldered gap (Tab. 7). The worked out means of vacuum brazing of WC-Co ISO K05 sinter plates and precipitation hardened stainless steel 14-5 PH on a large surfaces was verified in practice. On the basis of results of brazing tests a construction of the spinneret and a way of completing of the cutting layer were developed (Fig. 20). A shape, dimensions and the means of alignment of sinters plates were verified in the tests. The requirements concerning to the plates kind and the means of brazing with precipitation hardened stainless steel were determined. As a result of testing, the demands concerned to the vacuum brazing procedure of precipitation hardened stainless steel 14-5 PH large elements with of WC-Co ISO K05 sinters plates on large surfaces have been determined. They are mentioned as the conclusion.

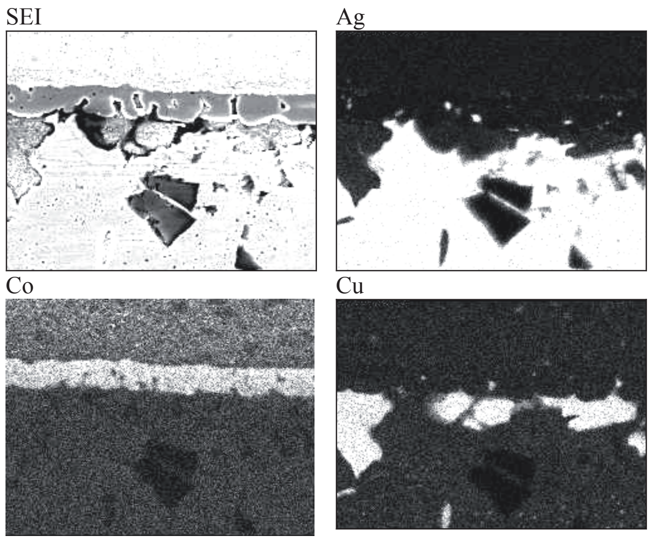

Fig. 13. Microphotography of a micro area of WC-Co ISO K05 sinter – Ag-Cu brazing filler metal – 14-5 PH steel joint (the plate site) and surface distribution of main chemical elements, magnification x1000

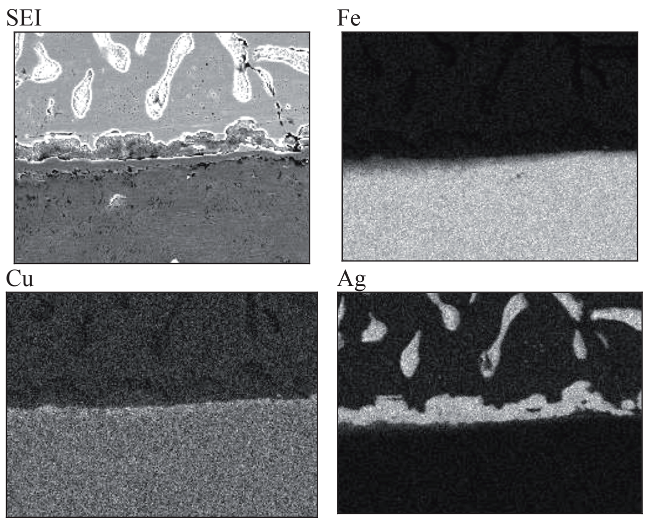

Fig. 14. Microphotography of a micro area of WC-Co ISO K05 sinter – Ag-Cu brazing filler metal – 14-5 PH steel joint (the steel site) and surface distribution of main chemical elements, magnification x1000

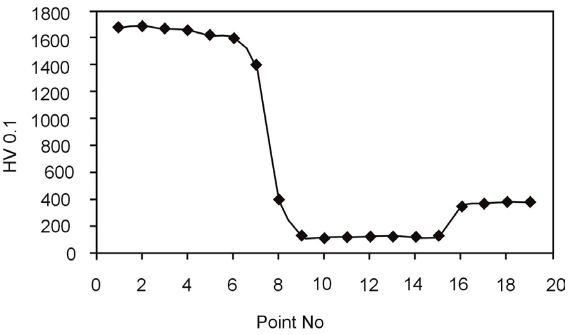

Fig. 15. Hardness HV 0.1 distribution of WC-Co ISO K05 sinter – Ag-Cu brazing filler metal – 14-5 PH steel joint cross section; points 1-6 – sinter, 7-16 – filler metal, 17-19 – steel

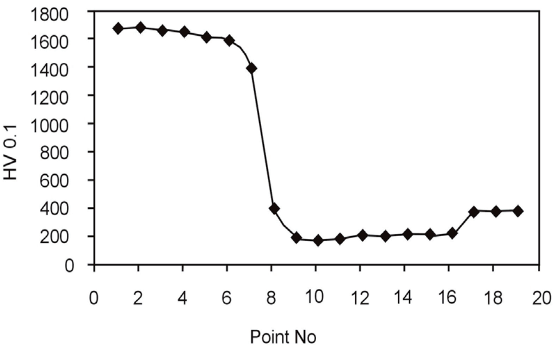

Fig. 16. Hardness HV 0.1 distribution of WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joint cross section; points 1-6 – sinter, 7-16 – filler metal, 17-19 – steel

Table 5.
Influence of the surface roughness Ra of the surfaces to be joint on a size of the brazed gap of the vacuum brazed WC-Co ISO K05 sinter – 14-5 PH steel joint, pressure exerted on sinters plates P = 200 Pa

Brazing filler metal	Means of machining and surface roughness Ra	Size of the brazed gap, mm
Cu	Milling, Ra = 4.08	0.09
	Grinding, Ra = 1.82	0.08
	Polishing, Ra = 0.08	0.06
Ag-Cu	Milling, Ra = 4.08	0.10
	Grinding, Ra = 1.82	0.07
	Polishing, Ra = 0.08	0.07

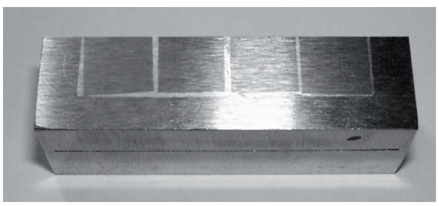

Fig. 17. Correctly completed WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joint

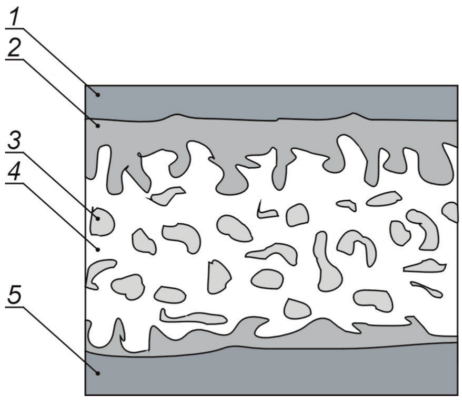

Fig. 18. Scheme of the joint structure WC-Co ISO K05 sinter – Cu brazing filler metal – 14-5 PH steel joint; 1 – WC-Co ISO K05 sinter (hardness 1660-1700 HV); 2 – diffusive zone reach in cobalt and iron (hardness 420-780 HV); 3 – brazing filler metal – intermetallic phase from the Fe-Co equilibrium system (hardness 440-800 HV); 4 – brazing filler metal – a solid solution reach in copper (hardness 250 HV); 5 – steel (hardness 350 HV)

Table 6.
Influence of pressure exerted on plates on a size of the brazed gap of the vacuum brazed WC-Co ISO K05 sinter – 14-5 PH steel joint, joint the surfaces roughness Ra

Brazing filler metal	Pressure exerted on plates P Pa	Size of the brazed gap mm
Cu	200	0.09
	300	0.07
	400	0.08
Ag-Cu	200	0.08
	300	0.06
	400	0.07

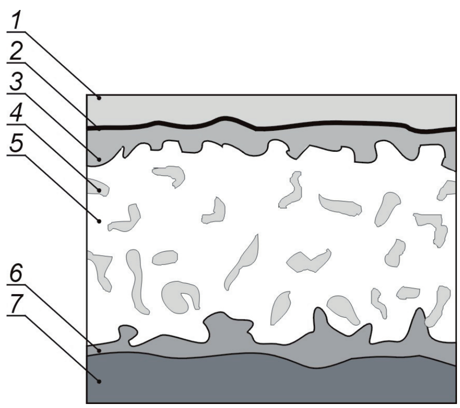

Fig. 19. Scheme of the joint structure WC-Co ISO K05 sinter–Ag-Cu brazing filler metal – 14-5 PH steel joint; 1 – WC-Co ISO K05 sinter (hardness 1660-1700 HV); 2 – diffusive barrier Ni; 3 – diffusive zone reach in Cu, Ni and Ag (hardness 400-800 HV); 4 – solid solution Ag-Cu rich in silver (hardness 160 HV); 5 – solid solution Ag-Cu rich in copper (hardness 400 HV); 6 – transient zone rich in Cu, Ni and Ag (hardness 260 HV); 7 – steel (hardness 350 HV)

Table 7.
Mechanical properties of vacuum brazed WC-Co ISO K05 sinter – 14-5 PH steel joints

Property	Size of the brazed gap mm	Brazing filler metal	
		Cu	Ag-Cu
Average shear strength R_t MPa	0.06	205.6	156.1
	0.10	167.1	122.2
	0.14	149.3	103.3
Average tensile strength R_m MPa	0.06	315.0	273.4
	0.10	276.5	225.7
	0.14	234.7	209.1

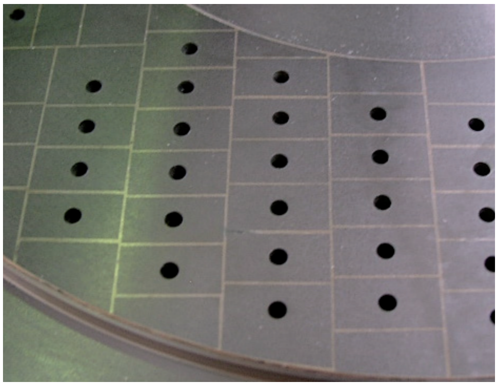

Fig. 20. A part of the die for polyethylene granulation with the surface of WC-Co ISO K05 sinters cutting plates brazed to the face die body within this investigation; working plates (with a hole), distancing plates (without a hole)

4. Conclusions

The worked out means of vacuum brazing of WC-Co ISO K05 sinters plates and precipitation hardened stainless steel 14-5 PH on a large surfaces assurances a good quality of the joint. As a result of diffusive processes in bounders of WC-Co ISO K05 sinter – brazing filler metal and steel – brazing filler metal, alloying components gradients, and some intermetallic phases have been created. It causes a diversification of microhardness in the joint cross-section, what can have an influence on joint ductility. The basic factors decreasing quality of the joint, which can occur while vacuum brazing of stainless steels and cermets are: diffusive processes leading to exchange of elements of cermets and the connection, low wettability of cermets, heterogeneity of a chemical composition, a structure and density of available cermets, Taking away of the mentioned defects is possible as a result of shortening of brazing duration to the smallest ones possible by technological reasons and application of low cooling rates after brazing. In order to ensure high quality of the joint the following is necessary:

- application of sinters plates of a possible high part of a metallic phase,
- selection of sinters plates as regarding surface defects, homogeneity of plates colours, presence of cracks and spallings,
- assurance of the soldered gap thickness of 0.2-0.4 mm through selection of a soldered surface roughness,
- application of nickel or cobalt layers increasing wettability of the cermets plates by brazing filler metal,
- thorough cleaning and degreasing of elements subject to brazing,
- strict reduction of oxides on surfaces subject to brazing through holding in vacuum,
- proper alignment of sinters plates,
- brazing of carefully horizontally placed and loaded sinters plates,
- a proper selection and optimization of brazing parameters aiming to reduction of temperature gradients and limitation of diffusive processes,
- possible short times and possible low brazing temperatures,
- slow heating up to brazing temperature with isothermal stops,
- slow cooling down after brazing,
- filling of possible discontinuities between sinters plates created during brazing with a brazing filler metal of a lower fusion temperature,

As a result of conducted experiments a production of spinning nozzle of a die for polyethylene granulation with a vacuum-brazed with a WC-Co ISO K05 sinters plates cutting surface of large surfaces on precipitation hardened stainless steel 14-5 PH have been worked out and industrial applied. Results of the numerical analysis of chosen brazed joint models made for a plate of 17 – 4 PH steel and WC - Co cermet brazed prov3ed that the joint thickness has an essential influence on the local value of stresses and the joint rigidity. With the increase of the joint thickness the joint rigidity decreases. Local stresses can change even of about a few hundred percent depending on the load manner [5].

Additional information

The presentation connected with the subject matter of the paper was presented by the authors during the 12th International Scientific Conference on Contemporary Achievements in Mechanics, Manufacturing and Materials Science CAM3S'2006 in Gliwice-Zakopane, Poland on 27th-30th November 2006.

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