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Brazing of 14-5 PH steel and Fe - TiC composite using AWS BNi2 filler metal

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Materials

ABSTRACT

Purpose: Purpose of this paper is description of influence of the parameters of the 14-5 PH steel and cermets - PM Fe-TiC composite plates brazing using nickel based brazing filler metal BNi2 structure and properties of joints.
Design/methodology/approach: Brazing was done in vacuum according to a special thermal cycle programme. Metallographic, X Ray analysis, microanalysis, hardness and tensile strength, as well quality investigations of produced joints have been done.
Findings: It was shown that The joint has a eutectic multilayer structure with a zone of intermetallic compounds in the steel – soldier and soldier – PM Fe-TiC composite - Ferro – Titanit plates boundary. Intermetallic compounds zone differ clearly on account of a chemical composition, microstructure, and hardness from a brazing filler metal matrix.
Research limitations/implications: It was shown that the diffusive zone from the PM Fe-TiC composite side is rich in titanium, molybdenum and iron, in the joint axis there is a zone rich in silicon, and in a boundary filler metal – steel rich in iron and nickel. In the rich in nickel and iron filler metal matrix, there are intermetallic phases rich in chromium, which consist several percent of nickel, iron and molybdenum. The diffusive zones are characterized by hardness higher than the filler metal matrix.
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 PM Fe-TiC composite plates cutting surface have been worked out and applied in industry.
Originality/value: An original value of the paper is to prove the propensity of concentration gradients of alloying components and intermetallic phases creation.
Keywords: Metallic Alloys; Materials; Welding

1. Introduction

Optimal use of cermets properties e.g. high hardness, frictional wear resistance, chemical and thermal resistance, while limiting their basic defect, which is small ductility, creates such designing of steel – cermet joints in machine and tool parts that eliminates or reduces significantly a presence of tensile stress. It requires a proper support of a small ductility element, most often as a result of joining with an element made of steel. The joints also have to fulfil a number of geometric joint enabling tightness of the construction or also a possibility of effective compensation of stresses caused by different values of thermal expansion coefficients of the joining elements. Brazed joints belong to these ones, which can fulfil the mentioned requirements and vast possibilities of control of joint's properties as a result of a selection of a brazing filler metal, joint geometry, means and parameters of brazing enable to join materials of various chemical constitution and properties. Methods improvement of optimal shaping of a structure and properties of a brazed joints remains in a close connection with research development over elementary phenomena occurring during the brazing process [1 - 4]. 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 e.g. WC – Co sinters or PM Fe-TiC composites which can be used in dies for polyethylene granulation [5, 6]. Contemporary brazed joints have to fill more and more sharper operation 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 cermets plates with a steel matrix on large surfaces occurs during production of cutting surfaces of dies for granulation of polyethylene. Vacuum brazed joints of cermets and stainless steels for spinning nozzle of a die for polyethylene granulation are ones of the most advanced ones. Still there are many aspects of the brazing process, particularly in respect to various chemical composition and properties materials, which need further investigations. In the midst of many factors deciding about a structure and properties of the connection, the fundamental importance has in this field: a brazing filler metal, means of brazing, size of a soldered gap. Strength and plasticity of the joint for a supposed composition of brazing filler metal show a distinct dependence on a size of the soldered gap [7 - 9].

The essential issue of designing of the brazing method of steel and cermets on considerable surfaces are joints quality problems, which 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,
- retaining 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 the 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 a change 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.

2. Experiment

Construction development of the die for polyethylene granulation with the cermets cutting surface of large dimensions have been a new and complex technological problem. It was preceded by numerous tests aiming to optimise the brazing technology in order to minimize mentioned unfavourable phenomena and assurance of acceptable quality of the joint. The investigations included: brazing tests, metallographic investigations of the joints and investigations of mechanical properties of the joints. Brazing tests of 14-5 PH steel and PM Fe-TiC composite plates - Ferro–Titanit Nicro 128 produced by Edelstahl Witten Krefeld Gmbh using nickel based filler metal BNi2/MBF 20 (AWS BNi2; AMS 4777B) have been carried out. Chemical composition and basic properties of materials used in the brazing process are presented in Tab. 1-5. 14–5 PH steel has high mechanical properties in room and in minus temperature. Corrosion resistance of 14–5 PH steel is comparable to corrosion resistance of typical stainless steel. The steel is usually used in production of machine parts, which should have particularly high mechanical properties and particularly good corrosion resistance. Parameters of heat treatment of 14–5 PH steel are analogous to parameters of brazing using BNi2/MBF 20 filler metal and parameters of heat treatment of PM Fe-TiC composites - Ferro–Titanit Nicro 128 Application of Ferro–Titanit Nicro 128 plates resulted their attractive technological and functional properties. PM Fe-TiC composites belong to a group of particles reinforced sintered metal matrix composites. PM Fe-TiC composites have a stainless steel matrix reinforced by titanium carbide particles. They have properties halfway of tool steels and halfway of WC – Co sinters. Depending on a nature of a matrix and its heat treatment state, properties of PM Fe-TiC composites may vary in a broad scope. PM Fe-TiC composites belong to a group of particles reinforced sintered metal matrix composites. The composites have 10÷20–time higher wear resistance than high-speed steels. A matrix chemical composition in currently produced PM Fe-TiC composites corresponds to a chemical composition of quenched steels, stainless steels and also of precipitation hardened by intermetallic phases alloys. Practically insoluble in steel matrix titanium carbide - TiC, play a role of the reinforcement in PM Fe-TiC composite. A volume fraction of a matrix in a sinter is higher than in WC – Co sinters and mostly exceeds 50 %. Therefore PM Fe-TiC composites are characterized by a considerably higher ductility than WC – Co sinters and, at the same time, repeatedly higher frictional wear resistance than tool steels. After sintering, PM Fe-TiC composite machine elements and tools are machined, hardened and tempered. Depending on a nature of a matrix and its heat treatment state, properties of PM Fe-TiC composites may vary in a broad scope. PM Fe-TiC composite can be produced either as a result of pressing and sintering of mixtures of TiC carbides and steels powders or as a result of saturation by melted steel of a provisionally sintered porous TiC skeleton. Well-known examples of semi-finished products made of PM Fe-TiC composite are rods, sleeves and plates with a matrix of precipitation-hardened steels reinforced by TiC. PM Fe-TiC composites have following features:

- possibility of machining of products in a softened state and hardening of a matrix as a result of a quenching,
- possibility of joining with numerous grades of steel, high frictional wear resistance, and for stainless steel matrix - high corrosion resistance,
- possibility of numerous renovation as a result of heat treatment and machine cutting, high homogeneity of structure and minor dimensional deformation while heat treatment,
- 50% lower density than a density of sintered carbides, and of 15% lower density than a steel density.

A basic structure of PM Fe-TiC composites consists of titanium carbide particles embedded in highly alloyed ferrite or martensite. PM Fe-TiC composites are applied as materials of: tools plastic forming and machine elements used in conditions of frictional, erosion, corrosion and thermal wear. Scheme and parameters of a brazing process and its thermal cycle are presented in Table 6. On produced joints were done: optical and scanning microscope metallographic tests on 3 seconds warm-etched in a reagent: HNO_3 – 15 ml, HCl – 30 ml, HF – 30 ml specimens, quality and quantity X ray microanalysis, hardness and tensile strength.

Table 1.
Chemical composition and properties of 14 –5 PH steel % [6]

Ni	5.0÷5.8
Cr	13.2÷14.7
Mn	0.5÷1.0
Nb	0.2 ÷0.7
Cu	1.2÷2.0
Mo	1.2÷2.0
Si	0.6
Ta	1.7
C	0.07
P	0.04

Table 2.
Selected properties of 14 –5 PH steel [6]

Tensile strength, Rm [N/mm]	647÷1470
Yield point, $R_{0.2}$ [N/m^2]	539÷1093
Elongation, A5 [%] min.	10÷23
Hardness, HRC	29÷40
Thermal conductivity, λ [W/mK]	17.165
Thermal expansion, α 10^{-6}[K^{-1}]	0.771

Table 3.
Chemical composition of BNi2/MBF 20 (AWS BNi2; AMS 4777B) brazing filler metal % [10]

Cr	B	Si	Fe	C	Ni
6.0÷8.0	0.75÷3.50	4.0÷5.0	2.5÷ .5	max.0.06	matrix

Table 4.
Chemical composition of PM Fe-TiC composite - Ferro–Titanit Nicro 128, acc. to Edelstahl Witten Krefeld Gmbh % [10]

TiC	Cr	Mo	Co	Ni	Fe
30.0	9	5	9	4	matrix

Table 5.
Selected properties of Ferro–Titanit Nicro 128 [10]

Density [g/cm^3]	Compressive strength [N/mm^2]	Bending strength [N/mm^2]	Modulus elasticity [N/mm^2]	Hardness HRC
6.5	2750	1200	294 000	62

Table 6.
Basic parameters of brazing

Speed of heating up [^{o}C/hour]	100
Isothermal stop while heating [^{o}C/hour]	1010/0.5
Brazing temperature [^{o}C]	1070 ÷ 1100
Brazing time [min.]	10
Atmosphere	Vacuum 10^{-3} Pa
Cooling speed from brazing temperature [^{o}C/hour]	100 ^{o}C/hour to 850 ^{o}C then fast cooling

3. Results

The nickel matrix BNi2/MBF 20 brazing filler metal shows a good adhesion to a surface, no oxides and discontinuities both of a steel side and plates of PM Fe-TiC composite - Ferro – Titanit, and no cracks in plates being a result of brazing. The joint has a typical for brazing filler metals eutectic structure with a zone of intermetallic compounds in the steel – soldier and soldier – PM Fe-TiC composite - Ferro – Titanit plates boundary. Intermetallic compounds zone differ clearly on account of a chemical composition, microstructure, and hardness from a brazing filler metal matrix (Fig. 1 – 2; Tab. 7). Obtained joints have a multilayer structure. In a boundary PM Fe-TiC composite – filler metal there are diffusive zones having a chemical composition different of a filler metal matrix. The diffusive zone from the PM Fe-TiC composite side is rich in titanium, molybdenum and iron, in the joint axis there is a zone rich in silicon, and in a boundary filler metal – steel rich in iron and nickel (Tab. 7). In the rich in nickel and iron filler metal matrix, there are intermetallic phases rich in chromium, which consist several percent of nickel, iron and molybdenum. The diffusive zones are characterized by hardness higher than the filler metal matrix. A size of a soldered gap, influenced on strength of the joint, depend on surface roughness and pressure on plates Tensile strength of the vacuum brazed of PM Fe-TiC composite and 14 –5 PH joint are strongly affected by a size of soldered gap (Tab.8).

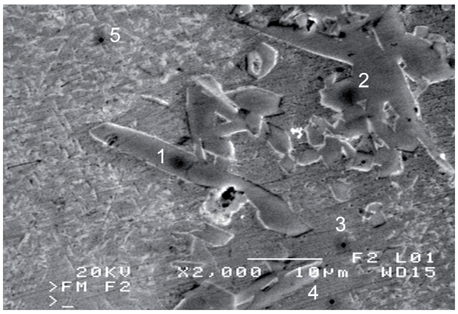

Fig. 1. Micro – area image of the PM Fe-TiC composite and brazing filler metal boundary, in which the point microanalysis was done, magnification 2000 x [6]

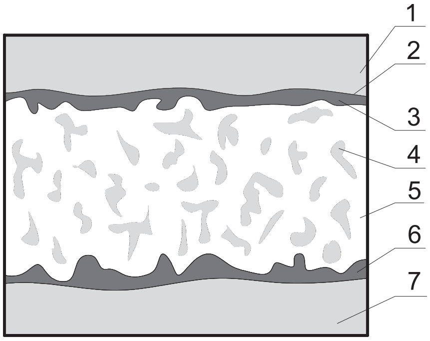

Fig. 2. Structure scheme of PM Fe-TiC composite and 14 –5 PH joint brazed by AWS BNi2 filler metal; 1 – PM Fe-TiC composite, 2 – zone rich in Ti, 3 – Ni diffusive barrier; 4 – intermetallic phase rich in Cr; 5 – solid solution Cr, Fe, Ni; 6 – diffusive zone rich in Cr, Fe, N; 7 – steel

Table 7.
Microanalysis of points marked on Fig. 1

No.	Micro area	Ni	Cr	Co	Si	Ti	Mo	Fe
1	intermetallic	1,66	90,55	0,15	0,11	0,43	4,56	2,53
2	intermetallic	2,77	88,28	–	0,16	0,49	5,02	3,29
3	solder matrix	71,10	3,42	1,9	4,11	0,12	0,14	19,20
4	solder – matrix	71,11	3,42	1,9	4,13	0,15	0,17	19,12
5	steel	70,17	4,71	1,91	3,1	0,3	–	19,72

Table 8.
Influence of the surface roughness Ra of the PM Fe-TiC composite plates on the size of soldered gap and average shear strength Rt of the PM Fe-TiC and 14 –5 PH joint, pressure exerted on plates P = 200 Pa

Means of machining and Ra	Size of the soldered gap [mm]	Average shear strength Rt [MPa]
Milling, Ra = 4,08	0.09	211.2
Grinding, Ra = 1,82	0.08	172.2
Polishing, Ra = 0,08	0.06	156.1

4. Conclusions

It have been found a propensity of concentration gradients of alloying components and creation of intermetallic phases in zone bounders of PM Fe-TiC composite – BNi2 brazing filler metal and 14 –5 PH steel. It causes a diversification of micro hardness in cross-section of the joint, which can have an influence on joint ductility. Taking away of the mentioned defects is possible as a result of limitation of brazing duration to the smallest one and application of low cooling rates after brazing. The worked out means of vacuum brazing of PM Fe-TiC composite plates and precipitation hardened stainless 14 –5 PH steel on large surfaces assured a good quality of the joint, what have been a subject of the other considerations [11 – 15]. As a result of experiments a production of spinning nozzle of a die for polyethylene granulation with a vacuum-brazed with a PM Fe-TiC composite plates cutting surface have been worked out and applied.

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