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VACUUM BRAZING OF TOOLS WITH A THIN FOIL

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The paper deals with a study of vacuum brazing of two or more workpieces made of tool steel using a thin foil. In the first part the problem is described and some fundamentals of vacuum brazing are given. In the second part the experimental procedure used in this paper is described. In the present study, specimens of tool steel were used. The specimens, between which a thin nickel-base foil of 0,05 mm in thickness was inserted, were pressed together in different ways while they were being brazed in a vacuum furnace. The pressing force varied during the experimental work. At the end findings, conclusions, and guidelines for future work are given. It was found that the pressing force between two workpieces has a major influence on the vacuum brazing process and properties of a brazed joint.

Key words: tool steel, vacuum brazing, nickel-base foil, vacuum furnace, heat treatment

INTRODUCTION

Vacuum brazing is a technology of joining metal elements made of similar or dissimilar materials. Brazing has been known and used in practical applications for a long time.

Vacuum brazing of tools for various purposes is, however, less known and less used in practical applications. According to the theory ob brazing a mechanical force of pressure applied to workpieces being joined does not affects the joining process itself. Also a theory of element diffusion states that the force acting between two substances does not affect the diffusion process. According to a Fick's law diffusion is affected only by temperature and a difference in substance concentration at two different points [1].

With vacuum brazing rapid prototyping of tools for various purposes is possible. This a relatively old technology, which however, is rarely used in practical applications. There are several reasons for this.

This joining process requires relatively expensive equipment and extensive technological knowledge on steels, material joining, brazing alloys and heat treatment of steels [2-9].

In addition to rapid prototyping of tools using the mentioned technology, it permits joining of materials of different quality and different chemical compositions. This means that in tool manufacturing a quality material can be used where there is active die, whereas the rest of the tool can be made of a lower quality material, which is cheaper [10-12]. The second important fact is that with brazing with a thin foil, ideally shaped cooling channels for cooling the entire tool can be manufactured.

The study is to indicate some basic options of brazing tools and establishing an influence of pressing force between two workpieces between which the nickel-base foil (brazing alloy) is inserted.

In the technical literature numerous articles, reports, guidelines, and books on vacuum brazing can be found. But the literature reporting the influence of the pressing force between the workpieces with a brazing alloy in between are discussed three references [13-15]. The major part of information and general instructions on vacuum brazing. A major part of literature reports vacuum brazing of various vessels, tanks, heat exchangers, electric components, and similar. Materials used for these products are stainless steel, zinc-coated plates, various non-ferrous metals, and others. Data on brazing of tool steel are rare.

EXPERIMENTAL WORK

As a base material AISI H13 chromium hot wotk tool steel for high pressure die casting of aluminium alloys was used [16]. As a brazing alloy a thin nickel-base foil with a thickness of 0,05 mm was used. Chemical compositions of the materials are given in the Table 1. Specimens were produced and pressed together with various forces while being brazed in a vacuum furnace. Also a special clamping device was manufactured in order to apply constant pressing force on the specimen.

Table 1 **Chemical compositions of the materials**

Base material / mass. %					
C	Cr	Si	Mo	V	Fe
0,38	5,00	1,00	1,30	0,40	rest
Brazing alloy / mass. %					
C	Cr	Si	B	Fe	Ni
0,04	6,60	4,60	2,90	3,00	rest

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Figure 1 shows the possibility to manufacture complex tool with the use of vacuum brazing technology. Different parts of the tools are arranged via ''lego'' system. Different parts of the tool can be produced of different materials and prefabricated, then vacuum brazing is used to join them using a thin foil. This joining process also offers the opportunity for unique positioning of the cooling chanels in order to increase the cooling rate of the part being produced resulting in higher production rates of the die casting process.

Experiments were carried out in vacuum furnace Sts Therms VWC 669–15 with a power of 130 kW, a maximum temperature of 1 300°C and an underpressure of 10^{-3} mbar.

During brazing the temperature was measured as a function of time. A K-type thermocouple was placed at the specimen to be brazed.

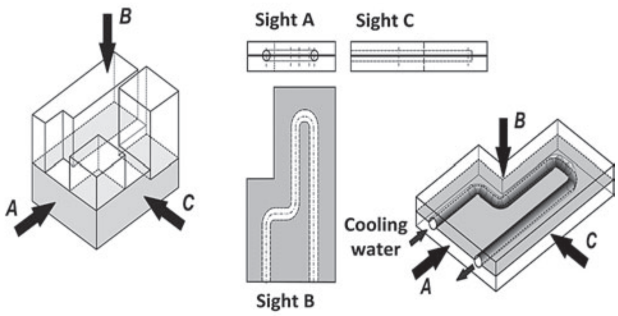

Figure 1 Application of vacuum brazing in the field of tool manufacturing.

SPECIMEN PREPARATION AND BRAZING

Initial studies of brazing parameters were made at specially prepared specimens. Figure 2 shows two specimens between which a thin foil is inserted as the brazing alloy. The specimens are made of tool steel as given in Table 1.

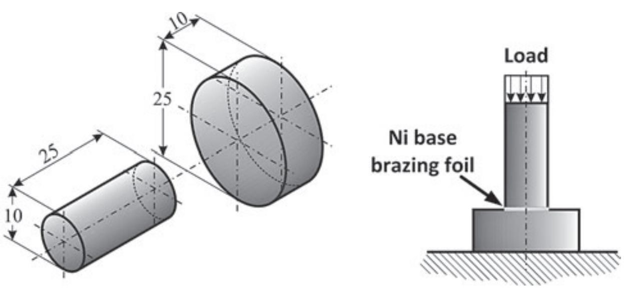

Figure 2 Specimens to study the influence of pressing force during vacuum brazing on strength and other properties of the joint.

In the experimental work positioning and clamping of specimens were carried out using special jigs. The authors were aware of the fact that a maximum brazing temperature was more than 1 000 °C and there is no suitable material available to make a jig to transmit the force required.

Figure 3 shows a jig for clamping i.e. providing a mechanical force at elevated temperatures because of different coefficients of linear thermal expansion at elevated temperatures. External frame (1) was made from martensitic steel with low coefficient of thermal expansion of $10 \cdot 10^{-6}$ m/mK. This material should be stiff enough to withstand the loads occurring inside the frame at the certain temperature. Internal element of the jig (2) was made of austenitic stainless steel with high coefficient of thermal expansion of $16 \cdot 10^{-6}$ m/mK. This element provides a force at an elevated temperature and should be stiff enough to withstand a compressive load. Two specimens (3, 4) were brazed using thin foil (5).

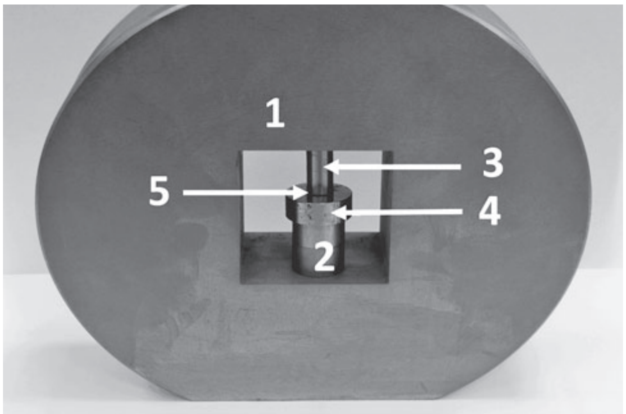

Figure 3 Jig for pressing the specimens, 1-frame of martensitic steel, 2 - internal element of the jig made of austenitic steel, 3,4 - specimens to be brazed, 5 - thin Ni base foil

The clamping force of the jig shown on the Figure 3 can be theoretically calculated if the physical properties of the materials are known. To measure it in practice is more difficult due to the high brazing temperatures. In order to provide a constant force of pressure during the brazing process joints were loaded with a weight in a

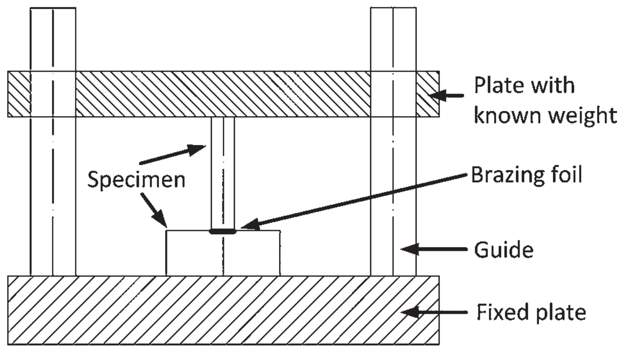

Figure 4 Schematic presentation of the experiment, applying loads to the specimen during vacuum brazing in furnace.

Table 2 **Applied loads on the specimens and pressures in the brazed joints**

Specimen Nr.	Load / kg	Pressure in the joint / MPa	Tensile strength of the joint / MPa
1	3,7	0,5	537
2	29	3,6	588
3	129	16,1	603

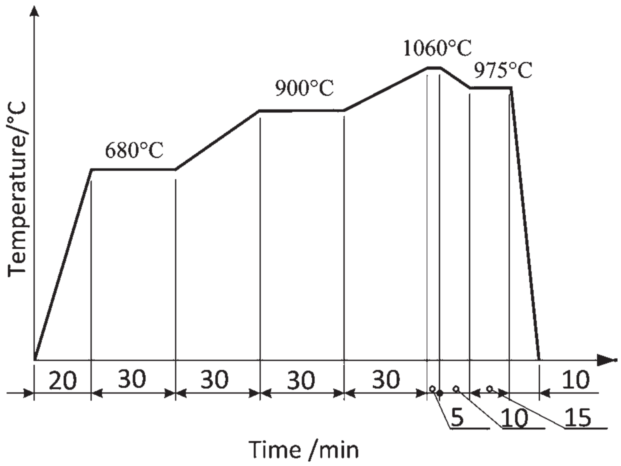

Figure 5 Thermal cycle of brazing and heat treatment to improve mechanical properties.

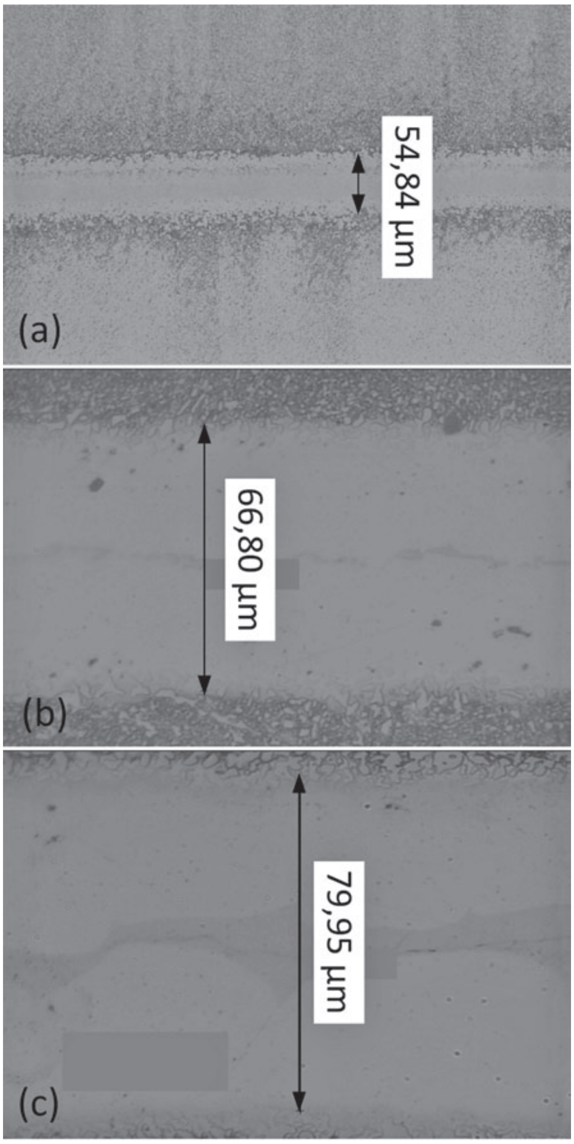

Figure 6 Macro sections of brazed joints according to the Table 2, (a) Specimen 1, (b) Specimen 2, and (c) Specimen 3.

form of a steel plate. Three different loads of 3,7 kg, 29 kg and 129 kg were used. Pressure applied on the brazed joint is numerically presented in the Table 2. Schematic presentation of the experiment is shown on the Figure 4. Thermal cycle for brazing is extremely important. If a tool is to be simultaneously brazed and heat treated a thermal cycle should be chosen according to the Figure 5.

Tensile strength of the specimens was measured at the normal room temperature of 22 °C. Results have shown that higher loads during brazing results in slight increase of the tensile strength and the value can reach up to 600 MPa.

EFFECT OF APPLIED LOAD ON THE GEOMETRY OF THE BRAZED JOINT

After brazing specimens brazed with different pressing forces were analysed. All other brazing parameters like temperatures and times were held constant for all of three specimens. Macro sections of the specimens were prepared in order to study the diffusion process and they are shown in the Figure 6. It is clearly seen the influence of the pressure on the diffusion process between the brazing material and parent metal.

The width of the joint between two specimens thus depends on the pressing force between two specimens. The brazing alloy contains about 82 mass.% of nickel which diffuses into the tool steel.

CONCLUSIONS

Above mentioned joining process offers new possibilities toward optimization of the tools operating at high temperatures. In order improve the properties of the joint between two specimens made from hot work tool steel different pressures were applied during the experimental procedure of brazing. Results have shown that the width of diffusion strongly varies when the joint is exposed to different loads during brazing. In this paper two different types of clamping devices were shown. If the material properties are known the load can be exactly calculated also for the jigs presented on the Figure 3, but in order to strictly monitor the brazing process the clamping device according to the Figure 4 is preferred. Tensile tests of the specimens have shown just a slight influence of the pressure on the tensile strength of the joint.

The results have shown that joint can reach the tensile strength up to 600 MPa which corresponds to the strength of the structural steels. Application of brazing in the tool manufacturing also offers an opportunity to make cooling channels effectively resulting in increased heat dissipation from the aluminium part during the casting process.

REFERENCES

[1] M. S. Mel, Brazing, ASM International, 2003.
[2] A. Srivastava, V. Joshi, R. Shivpuri; Computer modeling and prediction of thermal fatigue cracking in die-casting tooling, Wear, 256 (2004), 38-43.

[3] D. Klobčar, J. Tušek, B. Taljat, Thermal fatigue of materials for die-casting tooling, Mat. Sci. and Eng. A, 472 (2008), 198-207.
[4] D. Klobčar, J. Tušek, Thermal stresses in aluminium alloy die casting dies, Comp. Mat. Sci., 43 (2008), 1147-1154.
[5] M. Fazarinc, T. Muhič, G. Kugler, M. Terčelj, Thermal fatigue properties of differently constructed functionally graded materials aimed for refurbishing of pressure-die-casting dies, Engineering. Failure Analysis, 25 (2012), 238-249.
[6] G.E. Totten, M.A.H. Howes, Steel Heat Treatment Handbook, Marcel Dekker, New York, 1997.
[7] H.R. Shercliff, Modelling and Selection of Surface Treatments for Steels, Advanced Engineering Materials, 4 (2002) 6, 397 – 402.
[8] L.A. Dobrzanski, Technical and Economical Issues of Materials Selection, Silesian Technical University, Gliwice, 1997.
[9] B. Kosec, M. Brezigar, G. Kosec, J. Bernetič, M. Bizjak, Heat treatment of cold formed steel forgings for the automotive industry, Journal of Achievements in Materials and Manufacturing Engineering, 22 (2007) 2, 87 – 90.
[10] A. Košnik, J. Tušek, L. Kosec, T. Muhič, The manufacturing of a two-layered injection mold by welding, Metalurgija, 50 (2011), 2, 231-234.
[11] B. Kosec, L. Kosec, J. Kopač, Analysis of casting die failures, Engineering Failure Analysis, 8 (2001) 4, 355 – 359.
[12] A. Skumavc, J. Tušek, A. Nagode, L. Kosec, Tungsten heavy alloy as a filler metal for repair welding of tools for high pressure die casting, Int. J. of Mat. Res., 104 (2013), 1143-1150.
[13] B. Zorc, Reinforcement of brazed joints - Doctoral thesis, University of Ljubljana, Faculty of Natural Sciences, Ljubljana, 1999.
[14] M. R. Philip, Industrial brazing practice, Bocan Raton, CRC Press, (2004).
[15] B. Zorc, L. Kosec, Metallurgical reactions in the coalescence zone between a reinforcement and a parent metal in reinforced brazed joints, Metall, 58 (2004) 5, 290-294.
[16] J.R. Davis (Ed.), Tool Materials, ASM International, 1995.

Note: The responsible translator for English language is Urška Letonja Grgeta, Moar Prevajanje, Slovenia