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G. BOCZKAL*[#], K. DADUN*, P. PALKA*, A. HOTLOS*, M. JANOSKA*

STRUCTURE AND THERMOELECTRIC PROPERTIES OF INCONEL 625/Pt MICROJOINT

A method of using the electric charge in a capacitor was applied for the manufacture of thermocouple micro-joints. The motivation for the study was the need to produce a stable welded connection without affecting the geometry of the substrate, which was a thin sheet of Inconel 625 alloy (UNS designation N06625). Within the framework of the research work, a suitable workstation for micro-joints elaboration was built and welding experiments were performed using different electric charges. Studies carried out within the framework of the present work have shown that joints based on Inconel 625 alloy and platinum have the best application properties in the range of small-scale temperature measurements. They can be used, e.g., for monitoring the temperature distribution on the inner surfaces of electric motor casings. An undeniable advantage is in this case the high thermal resistance of both materials used to produce the joint, i.e. the Inconel 625 alloy and platinum. This allows them to be used at high temperatures under atmospheric conditions.

Keywords: Microjoint, Thermocouple, Microstructure

1. Introduction

Pressure welded micro-joints are widely used in electronics and precision mechanics. Their main advantages are small dimensions that do not exceed the size of the smaller joined element and also high durability resulting from the direct contact. This is a large advantage over the soldering technology, which additionally requires a low melting point binder. The most important disadvantages of pressure welding include the need to spend more energy to obtain partial fusion of both joined components and, contrary to soldering SMD (Surface Mount Device) components, the inability to lay simultaneously multiple welds. The choice of the joined components is also limited, since metals applicable for components joined in this way should exhibit mutual solubility in the solid state. In spite of this, in some applications such as the manufacture of thermocouple joints, pressure welding is unrivalled [1-6].

Pressure welding is a bonding process in which the bonded elements are brought into the state of partial fusion. No additional materials are used in this method, and the factor most important is the exerted pressure. At contact points, the flow of current through the pressure welded parts evolves large amounts of heat and results in partial fusion of both joined components. The disadvantage of industrial pressure welding is damage done to the surface of the connected materials by pressure of the welding electrodes and point heating of the entire cross-section of the produced joint [7]. This does not matter when the motor car body sheets are bonded but it does matter and is a serious problem in precision mechanics. The solution may be an alternative pressure welding technology that uses electric charges stored in the capacitor. Then the discharges are very fast and at the contact point of the two joined materials, in the time of a few microseconds, the flow of current measured in kA causes a precise local overlap of the joint zone without any deformation suffered by its external parts. This method allows for precise metering of the energy used to make the connection. The current is fed directly to the joined elements, which also eliminates the problem of electrode wear affecting the operating conditions of a welding machine. The problem in capacitive discharge pressure welding is ensuring the reproducibility of contact quality in micro-scale.

2. Methodology

The study was conducted on a 100 µm thick metal sheet of Inconel 625 alloy (Table 1) and 100 µm diameter platinum wire (99.997 wt%). The place of the joint was cleaned with ethyl alcohol prior to the pressure welding process. The electric charge was stored in a 2200 microfarad / 400 V capacitor. The welding system is schematically shown in Fig. 1. As a pressing element, a 2 mm diameter quartz rod was used. The pressure was exerted by the weight 100 g. The system works in open loop, with registration of discharge characteristics.

A conventional measuring system [8] was used to determine the thermoelectric characteristics. The reference temperatures at both ends of the tested thermocouple were measured with

* AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, FACULTY OF NON-FERROUS METALS, AL. MICKIEWICZA 30, 30-059 KRAKOW, POLAND

[#] Corresponding author: gboczkal@agh.edu.pl

TABLE 1

Chemical composition of Inconel 625 (wt.%)
(from *ASM Aerospace Specification Metals Inc.*)

Wt.%	Cr	Mo	Co	Nb+Ta	Al	Ti	C	Fe	Mn	Si	P	S	Ni
Min	20	8	—	3,15	—	—	—	—	—	—	—	—	rest
Max	23	10	1	4,15	0,4	0,4	0,1	0,5	0,5	0,5	0,015	0,015	rest

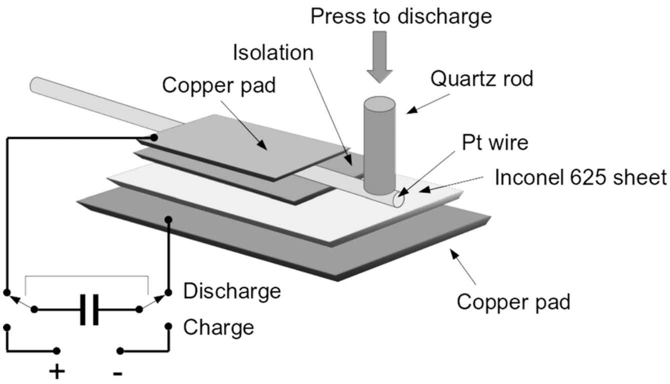


Fig. 1. Diagram of the system used for the manufacture of Inconel 625 / Pt micro-joints [10]

a CHY-502 K/J Thermometer measuring system provided with characteristic compensation and two K-type thermocouples. The measurement of the electromotive force at the cold end was made with an Agilent 34401A micro-voltmeter. Liquid nitrogen (77K), ethyl alcohol cooled with liquid nitrogen (173 ... 273K) and heated oil (300 ... 500K) were used as reference temperature media. The cold end was placed in distilled thermostated water at about 300K.

Microstructural studies were carried out using a Hitachi S3400N scanning microscope with the EDS detector of chemical composition. The studies included macroscopic observations of the prepared joints and cross-sectional analysis. Samples were embedded in conductive resin prior to analysis. Then they were ground until the face of the joint was exposed, and polished with the 0.04 μm SiC slurry. Tomographic sections of the joint were next obtained by grinding subsequent layers of the sample.

3. Sample preparation

The first phase of work was mainly devoted to the search for the optimum value of electric charge which would guarantee obtaining a stable joint. For this purpose, welding tests were carried out at different capacitive discharges, corresponding to the charging voltages comprised in a range from 14 to 22V (the capacitor charge was from 0.0308 to 0.048C). The results are shown in Fig. 3. The test performed at 14V, which corresponded to the capacitor charge of 0.0308 C, did not produce the required partial fusion of material in the joint zone, thus proving that the charge was insufficient to produce the connection. In samples welded at 16V (the capacitor charge was 0.0352 C), partial fusion of the material did occur but to a degree insufficient to produce the weld. The next test variant used the voltage of 18V (the capacitor charge was 0.0396 C). This variant was able to produce a stable connection as shown in Fig. 3, with distinct fusion of the platinum wire tip and partial melting of the substrate zone. It should be noted that despite the small thickness of the substrate, the sample did not suffer any deformation and the outside of the Inconel plate did not show any signs of fusion. The next voltage variant was 20 V (the capacitor charge was 0.044 C). In this variant, the electric discharge has caused a severe degradation of the substrate and melting down of the wire tip. The rapid discharge and high melting rate of the material produced metal vapours of high pressure in the micro-zone and it was this pressure that made the joint break. The last test was conducted at 22V (the capacitor charge was 0.0484 C). The result was heavy metal splashing combined with melting down and evaporation of the wire tip making the joint formation impossible (Fig. 2).

4. The weld microstructure

Fig. 3, shows the microstructure of Inconel 625/Pt joint obtained with a charge of 0.0396 C, which corresponds to 18V on the capacitor. The fusion zone of about 100 μm diameter, marked by dashed line in Fig. 3, was obtained, and it was sufficient to produce a stable connection. For the resulting joint, a tomo-

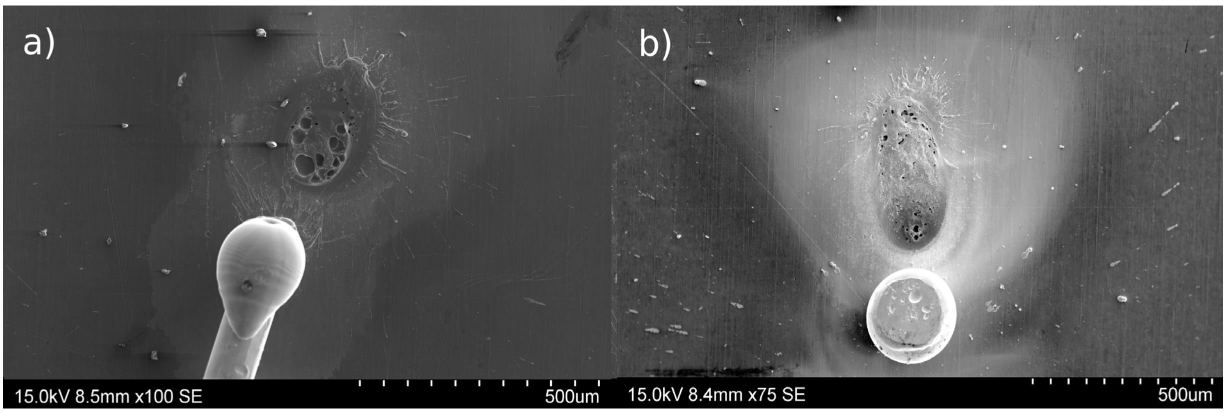


Fig. 2. Microstructure showing the results of the application of excessively high electric charge to produce the Inconel 625/ Pt microjoint: a) variant for a charge of 0.044 C (U = 20 V), b) variant for a charge of 0.0484 C (U = 22 V)

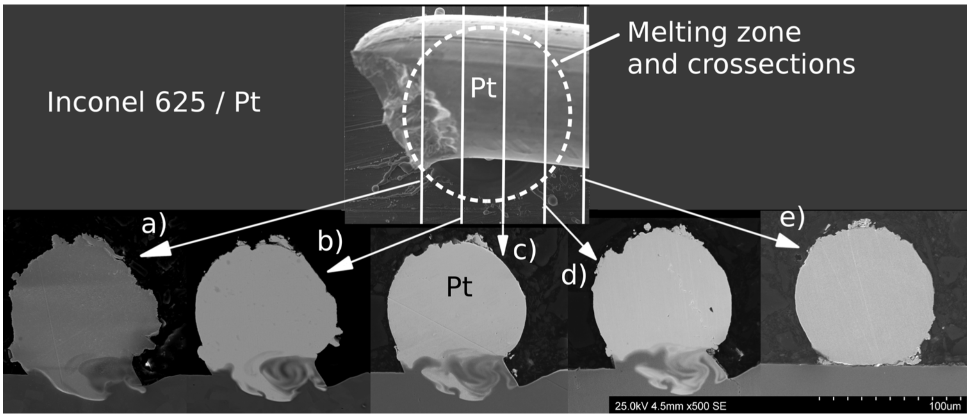


Fig. 3. Microstructure of the joint produced with an electric charge of 0.0396C (U = 18V); note the marked area of fusion, places where cross-sections were made and cross-sectional microstructure

graphic analysis was performed examining the cross-sections shown in Fig. 3a-e. It is evident that the joint components are strongly mixed in the fusion zone of the substrate material. At the same time, the thickness of the fusion zone in the substrate material does not exceed 20 μm, which allows avoiding the mechanical distortion.

The two main components of the joint are nickel, which is the primary constituent of the Inconel 625 alloy, and platinum. As shown by the phase diagram in Fig. 4a, both Ni and Pt form a solid solution with unlimited solubility [9]. Fig. 4b-d show mappings of nickel and platinum distribution in the weld cross-section. Strong mixing of the joint components is evident. The EDS point analysis of the chemical composition (Fig. 5) shows that the fusion zone comprises the solution composed mainly of four metals, i.e. iron, chromium, platinum and nickel. From the analysis of phase diagrams it follows that iron, nickel and platinum exhibit good mutual solubility in the liquid state. In contrast, chromium is combined with iron, while with nickel and platinum it tends to form phases or boundary solutions.

The short time of pressure welding did not allow obtaining the structure homogeneous in terms of the chemical composition [10].

The experiment leads to the rapid solidification similar to that described in [11]. In the case of rapid solidification solute

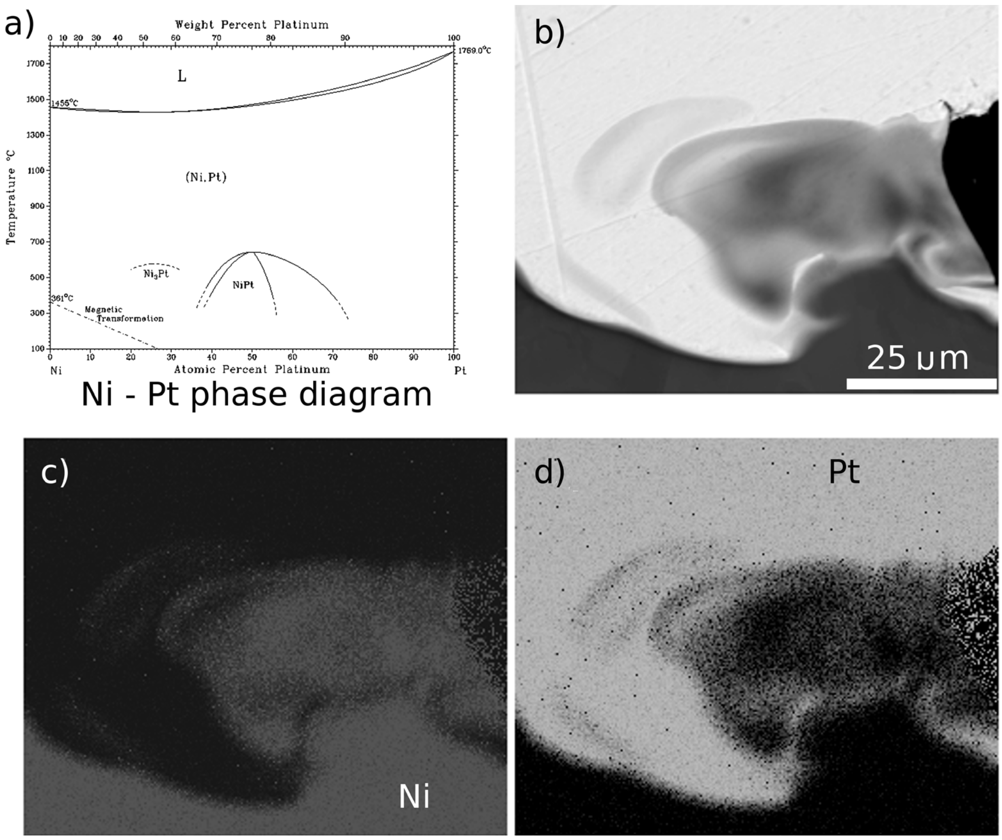
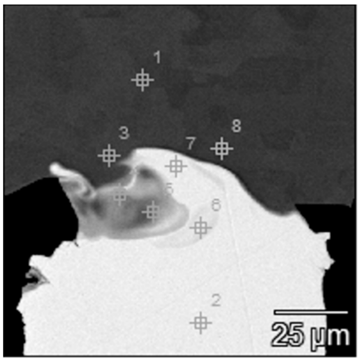


Fig. 4. a) the Ni-Pt phase system; b) the microstructure of Inconel 625/Pt joint in the central part of the fusion zone; c) nickel distribution in the weld; d) platinum distribution in the weld



Wt.%	Cr	Fe	Ni	Pt
Pt 1	16.37	9.69	73.93	
Pt 2				100.00
Pt 3	16.52	9.65	73.83	
Pt 4	9.37	5.63	44.76	40.24
Pt 5	10.71	6.22	52.12	30.95
Pt 6	1.02	0.69	3.78	94.50
Pt 7	0.01	0.34	1.10	98.55
Pt 8	16.26	9.42	73.11	1.21

Fig. 5. The results of point analysis of the chemical composition (wt.%) at various spots of the Inconel 625/Pt joint

partition ratio *k* tends towards unity: $k \rightarrow 1$. When $k = 1$ then solidification path is equal to nominal solute concentration, and the solidification process occurs without partitioning, [12].

This phenomenon is typical for all dynamic processes. However, the analysis of the mutual solubility of the joint components suggests that during operation at high temperatures as a thermocouple, the chemical composition will be homogenized by solid phase diffusion.

5. Thermoelectric characteristics

Detailed examination of the thermoelectric characteristics of the joint shown in Fig. 6 has proved its full applicability in a temperature range from 77 K up to the conditions limited by the thermal resistance of the components used. In practice, in the case of Inconel 625/Pt joints, the temperature limit is above 1700 K. The characteristics show high linearity and the thermocouple constant of 0.006 mV / °.

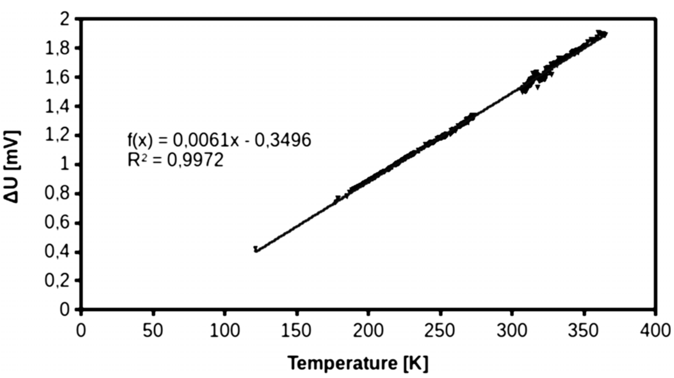


Fig. 6. Thermoelectric characteristics of the Inconel 625/Pt joint

6. Summary

Studies have shown that Inconel 625/Pt micro-joints obtained by the capacitive discharge pressure welding are characterized by stable microstructure and good thermoelectric properties. The quick process did not allow diffusion alignment of the composition in the joint.

The construction of the weld is the result of the discharge characteristics of the capacitor and consequently the Joule heat that melts the system components.

Detailed examination of the characteristics indicates the possibility of using these micro-joints in a temperature range from 77 K to about 1700 K. The pressure welding process with strictly defined electric charge allows the micro-joint to be made without any harm to the substrate geometry. In the case under study, the Inconel sheet was melted only to a depth of about 20 µm, with the micro-joint active surface estimated at 50% of the cross-section of the platinum wire used. This provides good mechanical strength and stable electrical performance.

Acknowledgement

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