Influence of Brazing Process Parameters on the Mechanical Properties of Nickel Based Superalloy

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Abstract

A common nickel based superalloy Inconel625 was brazed with Ni-base braze filler material (AMS4777) containing melting-point-depressants such as B and Si. Different braze gaps, brazing times and forms of braze filler material were tested. It was determined that the melting point depressants B and Si tend to form hard and brittle phases in the joint during the braze cycle. Brittle phases significantly reduce mechanical properties (e. g. tensile strength) of the joint. Therefore it is important to define optimal process parameters to achieve high strength joints, free of brittle phases. High ultimate tensile strength (UTS) values can be obtained if the joint area is free of brittle phases, which is equivalent to a complete isothermal solidification of the joint. Isothermal solidification takes place only if the concentration of the melting point depressant in the braze filler material of the joint is continuously reduced by diffusion into the base material. For a given brazing temperature, long brazing times and small braze filler material volumes (small braze gaps) are beneficial for isothermal solidification. On the base of the obtained results it can be stated that the form of the braze filler material has an additional influence on the joint quality. Better properties can be achieved by the use of braze-filler-material in form of foil instead of braze-filler-material in form of paste due to a reduced amount of voids and a more homogenous braze-filler-material-composition in the braze-gap by using foil

1. Introduction

INCONEL 625 is an austenitic nickel-chromium alloy having an excellent resistance to corrosion and oxidation, as well as good strength and toughness at high temperature. Typical applications include aero engines non-rotating components [1]. High temperature brazing is a common process and way to join this superalloy [2] - [8].
Brazing is an alternate joining process to welding. The preferred use is for joining different materials, big joining areas or long joining gaps. The main differences between welding and brazing is, that the base material isn't melted by external heat-input and the braze filler-material has a lower melting point, than the material to be joined. In general braze-filler materials contain **M**elting-**P**oint-**D**epressant elements such as boron or silicon. During the braze-process under a constant braze-temperature the MPD's diffuse in the surrounding base-material. Thus the braze-material in the braze gap more and more gets poor of the melting point depressants, what results in a continuous isothermal solidification of the braze-filler-material from each surface of the joining-members to the middle of the braze gap. For sufficient times at braze-temperature a complete isothermal solidification of the braze joint can be realized, what results in good braze-joint-properties. For (usually used) short times at braze-temperature remaining contents of the MPD's in the middle of the braze joint form hard eutectic structures containing very brittle intermetallic phases (with nickel and chromium) which are detrimental to the mechanical properties of braze-joints.
The selection of the brazing temperature depends on the type of filler material and on the materials to be joined. For the nickel based superalloy Inconel 625, a most common braze filler material used is AMS4777 [3], [4]. The advantage of this braze-alloy is, that it can be brazed at lower temperatures beginning from 1040 °C [5]. The Inconel 625 is usually used in the annealed condition, which is realized by heat-treating between 870°C and 980°C for 30 min. Brazing temperatures above this region will deteriorate mechanical properties of the material and the time required to complete isothermal solidification will have an additional impact on the properties of the material. In practice, a braze gap below 100 µm is usual but approx. 50 µm is preferred for better joint-properties. Thus, for better understanding of the process, parameters such as braze gap, brazing time and the form of the braze filler material were varied and experimental investigations performed.

The objective of this work was to develop a brazing process in order to achieve high strength joints of Inconel 625 with AMS4777 filler alloy. The effect of the process variables (time, braze gap and form of brazing), at a defined brazing temperature, on the joint microstructure and tensile properties was investigated.
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2. Experimental procedure

Wrought Inconel 625 samples in annealed condition were butt-brazed by using commercially available AMS4777 braze filler material with the following composition: Ni-7.0Cr-4.1Si-3.0B-3.0Fe. Different braze gaps of 25 µm, 50 µm and 100 µm were taken into consideration. Two different forms of braze filler material have been tested: powder resp. paste and amorphous foil. All braze-specimens were processed in a standard vacuum furnace at a pressure below 10^{-5} mbar. The samples have been brazed at a nominal temperature of 1050°C (furnace-tolerance at braze temp. ± 8°C) with different soak-times/braze-times as shown in Table 1.

Table 1: Brazing process parameters

Braze gap (µm)	*Time at braze-temperature(min)*					
	paste	foil	paste	foil	paste	foil
25	10	10	60	60	120	120
50	-	10	-	60	-	-
100	10	10	60	60	120	120

On these specimens tensile tests have been performed at **R**oom **T**emperature, 600°C and 700°C. Figure 1 presents a typical brazed specimen for tensile testing. The mechanical properties shown are an average out of 3 specimens.

Figure 1: Butt-brazed specimen for tensile testing

The tested specimens always failed in the braze joint. The broken specimens have been investigated by metallographic cut-up's and SEM to find out the failure-mechanism.

3. Results and discussions

For the combination of Inconel 625/Inconel 625 brazed with AMS4777, high UTS values are reachable (higher then 50% of base material strength) if the joint is free of brittle phases. When brittle phases are in the joint, the UTS is severely reduced .

Figure 2 presents the relative UTS obtained from specimens brazed at 1050°C for 10min with different braze-gaps and braze filler material forms. No matter which form of the braze filler material was used, the joint with 100 µm gap failed at a low and similar value of UTS. Microstructure investigation of these joints revealed a large number of brittle phases in the middle of the braze joints (see Figures: 5, 6). Decreasing the braze gap of the joint provides a higher strength which even can be increased by using foil instead of paste as a filler material (Figure 2). Higher values of UTS for joints with 25 µm gap are the result of complete isothermal solidification of the braze joint. Microstructure investigation of joints with 25 µm braze gap and at 10 min braze time revealed no or small amount of brittle phases (Figures: 11, 12).

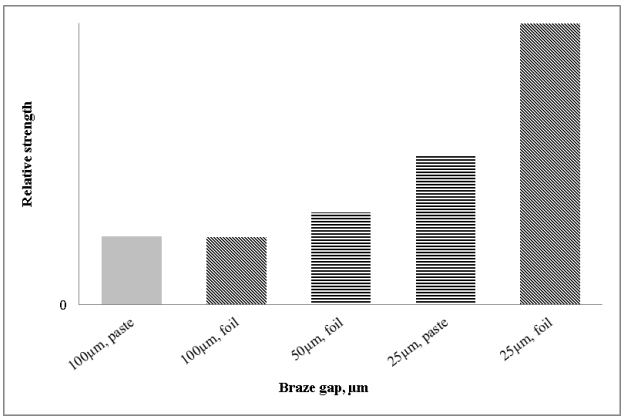

Figure 2: Relative strength of Inconel 625-specimens butt-brazed with AMS4777 as a function of braze-gap and braze-filler-material-form

The highest UTS-values for joints with 25 µm braze gap and 10 min. brazing time were obtained for the joint brazed with AMS4777-braze-foil

Regarding the influence of the braze-filler-material form it can be stated that by using braze foils, the time at temperature to reach a complete isothermal solidification of the joint is lower than by using braze paste. Using braze foil the content of the melting-point depressant element of the braze-melt in the braze-gap is the same than in the nominal braze filler material composition. In the case of braze paste, the content of the melting-point depressant element in the braze-gap is higher than in the nominal braze filler material composition. This is caused by different concentrations in the solid- and liquid-phases according to the relevant phase-diagram of the braze-filler-material. The use of braze-foils also leads to a reduction of voids in the braze-joint.

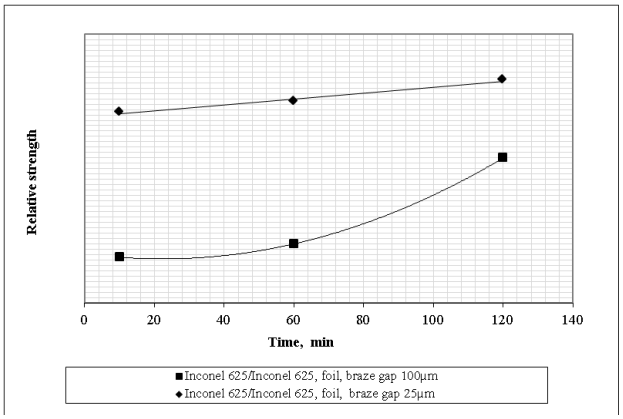

Figure 3: Influence of brazing time on the Relative UTS at RT of braze joints with different braze gap: 25µm and 100µm

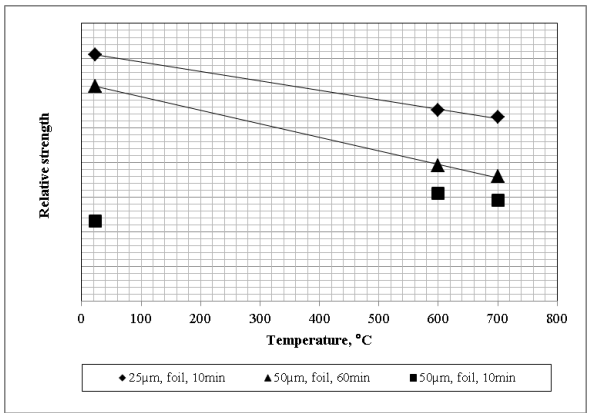

Figure 4: Influence of the test-temperature on the Relative UTS of braze joints with braze gaps of 25 µm and 50 µm and braze-time of 10 and 60 min 100µm

Joints with 100 µm braze gap, which were brazed for 60 and 120 min, exhibit UTS at Room Temperature at different and moderate levels (Figure 3). Microstructural examinations of joints brazed with braze-foil for 60 min. show a smaller amount of brittle phases than those brazed the same time with braze-paste (Figures: 7, 8). Longer braze times of 120 min produced completely isothermal solidified braze joints (Figures: 9, 10).

The increase in UTS for joints of 25 µm braze gaps with prolongation of brazing time from 10 to 120 min is not so significant (see Figure 3). The small volumes of braze filler material (small braze gaps) are beneficial for isothermal solidification and the time for obtaining this state is much shorter. The microstructure of joints with a 25 µm gap and brazed for 10 min. are shown in Figures 11, 12.

The dependence of relative UTS properties on the tensile-test temperature in different brazing conditions is presented in Figure 4. Highest values of UTS were obtained for the joint with 25 µm braze gap, brazed for 10 min. Lower values were obtained for the joint with 50 µm braze gap, brazed for 60 min; the joint showed a microstructure free of brittle phases. Different behavior was shown by the sample with 50 µm braze gap, but brazed only for 10 min, especially at RT. UTS at RT was lower then at a 600 and 700°C.

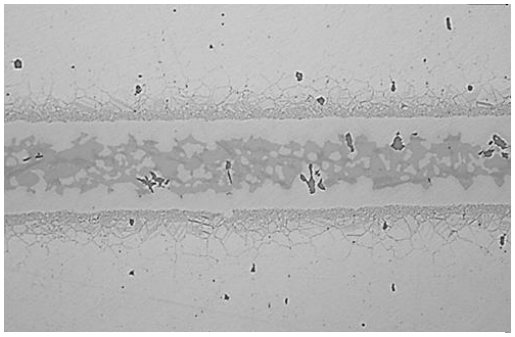

Figure 5: Microstructure of a braze-joint with AMS4777 paste at 1050°C for 10 min with a 100 µm braze gap

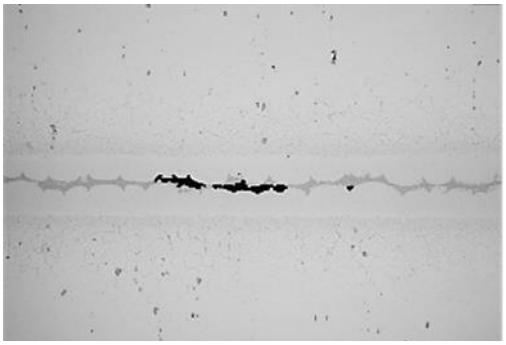

Figure 6: Microstructure of a braze-joint with AMS4777 foil at 1050°C for 10 min with a 100 µm braze gap

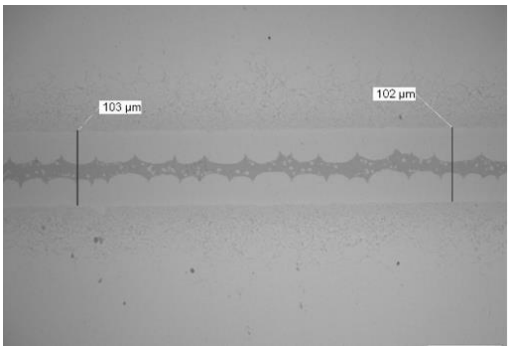

Figure 7: Microstructure of a braze-joint with AMS4777 paste at 1050°C for 60 min with a 100 µm braze gap

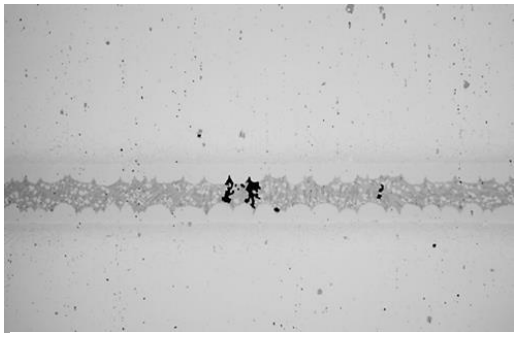

Figure 8: Microstructure of a braze-joint with AMS4777 foil at 1050°C for 60 min with a 100 µm braze gap

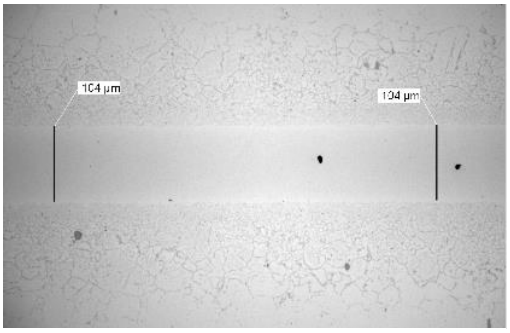

Figure 9: Microstructure of a braze-joint with AMS4777 paste at 1050°C for 120 min with a 100 µm braze gap

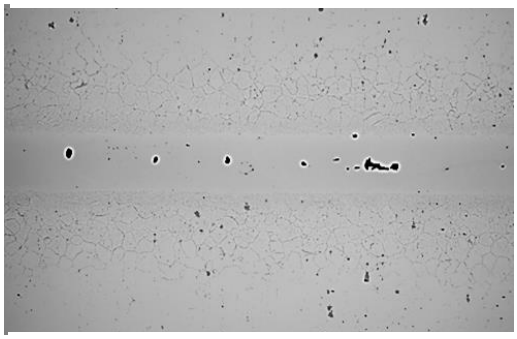

Figure 10: Microstructure of a braze-joint with AMS4777 foil at 1050°C for 120 min with a 100 µm braze gap

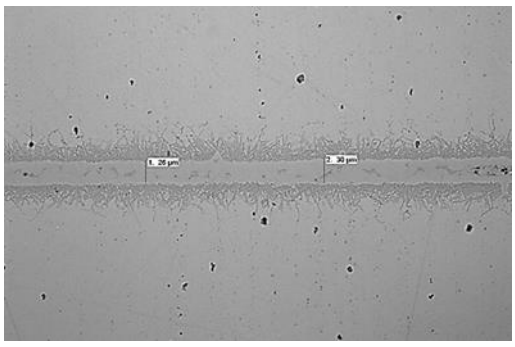

Figure 11: Microstructure of a braze-joint with AMS4777 paste at 1050°C for 10 min with a 25 µm braze gap

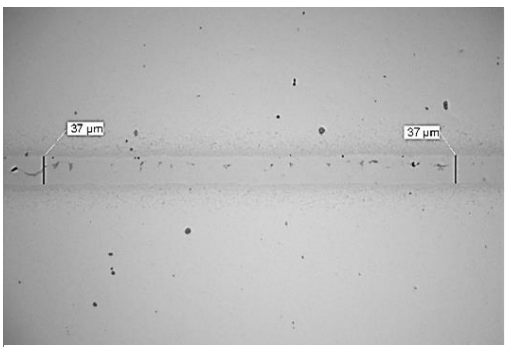

Figure 12: Microstructure of a braze-joint with AMS4777 foil at 1050°C for 10 min with a 25 µm braze gap

Fracture and microstructure investigation of specimen after tensile test were performed (see Figures: 13-16). The appearance of the fracture surface of the UTS with a braze gap of 50 and 100 µm indicates a crack growth path provided by a continuous path of brittle phases (Figure 15). In the case of samples with the 25 µm gap and completely isothermally solidified, fracture path occurred mainly through the diffusion zone of the braze material (see Figure 16), sometimes through grain boundaries of the joint.

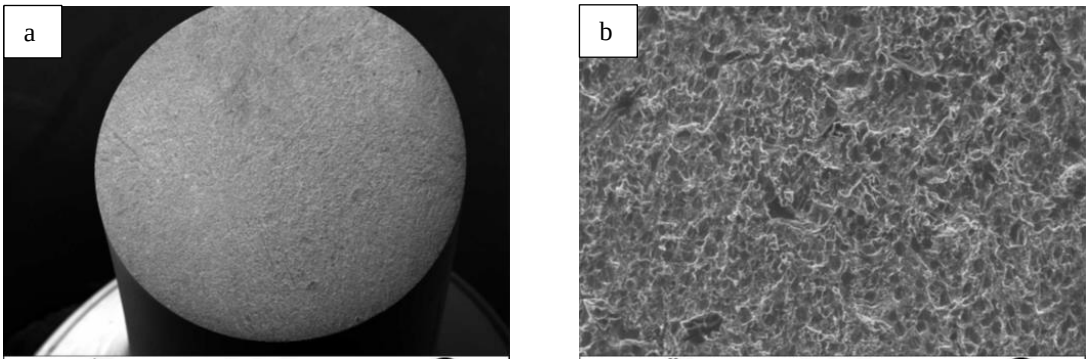

Figure: 13: Fracture of the joint brazed at 1050°C for 10min with 50 µm braze gap by the use of AMS4777 foil after tensile test at 600°C, magnification: a) 20x, b) 500x

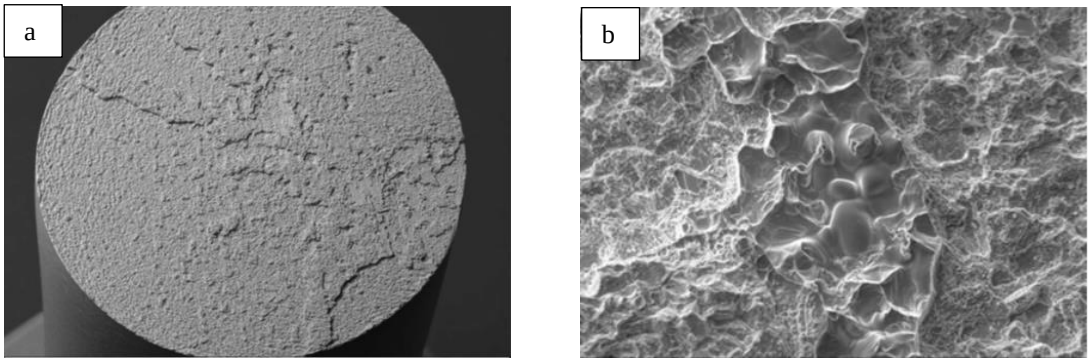

Figure 14: Fracture of the joint brazed at 1050°C for 60min with 50 µm braze gap by the use of AMS4777 foil after tensile test at 600°C, magnification: a) 20x, b) 500x

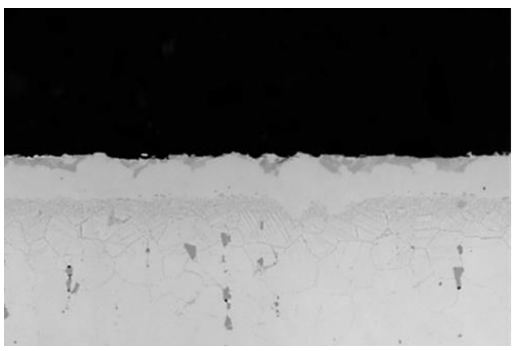

Figure 15: Microstructure of the cross section of the joint brazed at 1050°C for 10 min with 50 µm braze gap by the use of AMS4777 foil after tensile test at 600°C in the middle area of the joint

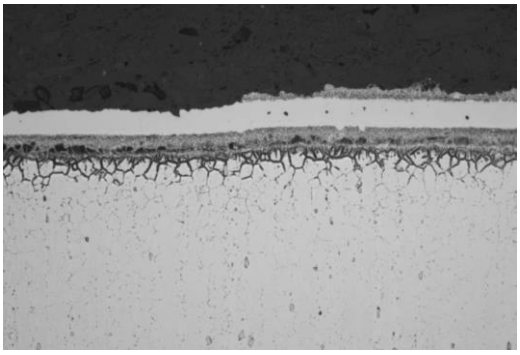

Figure 16: Microstructure of the cross section of the joint brazed at 1050°C for 60 min with 50 µm braze gap by the use of AMS4777 foil after tensile test at 600°C in the middle area of the joint

4. Summary

Various factors such as the joint gap width, brazing time and the form of the braze-filler-material (foil or paste) influence the microstructure and the tensile strength of a braze joint.
Attractive strength of Inconel 625 brazed with AMS4777 at 1050- 1060°C can be achieved by using braze foils, a narrow and uniform gap width of about 25 µm and a time at braze-temperature of about 10 min. to get a complete isothermal solidified braze joint. The UTS at RT of such a joint is about more than 50% of the strength of the base material. The microstructure is essentially free of brittle phases. However, such narrow braze gaps are difficult to maintain under realistic conditions in the manufacturing. When the width of the braze gap is 50 µm, the time to achieve the joint free of brittle phases is about 60 min.
Lowest strength and higher scatter of results must be expected when brazing with 100 µm braze gap, which is easier to manufacture. Such a braze gap needs a time of about 120 min to achieve a joint free of brittle phases, which is in many cases not economical. Although the joint is completely isothermal solidified, the UTS at RT of this joint is still lower compared to the strength of 25 µm wide joints.

Summarized, high-strength braze-joints can be realized by producing a joint, which is completely isothermal solidified. This can be economical realized by using braze-filler-material in form of foil, facilitate a narrow braze gap and braze for a sufficient time at a defined braze-temperature.

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