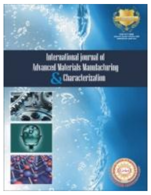

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Dissimilar Joining of Heat Treatable Copper alloy with Stainless Steel

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A R T I C L E   I N F O

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A B S T R A C T

Precipitation hardening stainless steel and copper chromium zirconium alloy are age hardening materials used in ITER, aerospace and plasma physics. Dissimilar vacuum brazing was carried after in solutionised condition to retain the maximum possible mechanical properties of both the alloys. A novel differential temperature vacuum brazing method coupled with heat treatment was evolved for the same and proved by experiments. The brazing experiment was carried out with a special heater + furnace assembly where the precipitation hardening stainless steel part was at 1040°C and copper chromium zirconium alloy part was at 980°C which where matching with solutionising temperature of both the alloys. Immediately after brazing (brazing cycle = solutionising cycle) the samples were quenched from brazing temperature by inert gas. Filler material used in the study was gold-18% nickel alloy. Aging treatment was carried out at 496°C for 4 hours after brazing. Parameters for maximum joint strength and maximum mechanical properties of precipitation hardening stainless steel and copper chromium zirconium alloy were arrived and discussed in detail. Resultant joint strength, microstructure and hardness results were included

Introduction

UNS 17400 is Precipitation Hardening Stainless Steel (PHSS) that is used in age hardened condition. It is one of the high strength materials and used up to medium temperature applications [1]. Main applications of this alloy are corrosion resistance parts in range of environments, stress corrosion cracking prone parts, and high strength parts. They include gears, valves and other engine components, high strength shafts, turbine blades, mouldingdies, nuclear waste casks [1, 4].UNS 17400 is Precipitation Hardening Stainless Steel (PHSS) that is used in age hardened condition. It is one of the high strength materials and used up to medium temperature applications [1]. Main applications of this alloy are corrosion resistance parts in range of environments, stress corrosion cracking prone parts, and high strength parts. They include gears, valves and other engine components, high strength shafts, turbine blades, moulding dies, nuclear waste casks [1, 4].
UNS 18500 is Copper Chromium Zirconium (CuCrZr) alloy which is age hardenable is widely used in special applications like high temperature heat transfer elements (active cooling applications) for ITER (International Thermo nuclear Experimental Reactor) and resistance welding electrodes [2]. These alloys cannot be joined by conventional methods because of metallurgical nature and poor joint strength by conventional methods. In fusion welding high intensity beam processes like EBW in solutionised condition can be applied to join them. [2,3].Aging treatment should be carried out after welding. But welding haslimitations when both alloys need to be joined as dissimilar joint and complex shapes. To overcome the problems vacuum brazing can be applied for these alloy combination [4]
Vacuum brazing is the most useful method in joining tiny and complicated parts, particularly in areas of aerospace, electronic and space applications [2, 3, 4]. An often over-looked ability of vacuum brazing is to simultaneously combine three metal treatments – bonding, cleaning, and heat-treating in one step. Brazing filler material is the most critical part of vacuum brazing. One of the important advantages of vacuum brazing, the joint strength, is possible by using most suitable filler material [3].

As PHSS and CuCrZr are age hardenable alloys as per the tables 2 and 3, any brazing operation in the temperature different form solutionising/ageing temperature can make the mechanical properties of the alloys to lose. In conventional vacuum brazing (slow heating and slow cooling or brazing at a temperature different from the heat treatment temperature) mechanical

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properties of CuCrZr alloy are affected [2,3, 5] and cannot be recovered fully by post brazing heat treatments. To overcome the loss, brazing cycle should match with solutionising cycle. The brazing filler alloy should be selected to have the brazing temperature in that range. For PHSS, most suitable brazing temperature (solutioning temperature) range is 1040-1060°C and for CuCrZr alloy, it is 900-980°C. One of the suitable filler materials is gold nickel; BNi, copper manganese nickel are other possible filer materials [6, 7].

Dissimilar joining of heat treatable alloys is one of the most difficult task in joining, if the dissimilarity is more, problem arise is maximum [7]. Particularly mechanical properties are affected by heating cycle, which evolves during joining. If the cases are for joining (by furnace brazing, vacuum brazing) PHSS with a CuCrZr alloy, the following problems occur

1. CuCrZr alloy melting point/brazing temperature is lower than PHSS. So the vacuum brazing temperature needs to be kept low. This makes mechanical properties of PHSS deteriorating.
2. Filler material selection is narrow as it should match with complete dissimilarity metallurgically and temperature.
3. Heat treatment temperatures are different, resulting in complicated brazing cycle.
4. Post brazing heat treatment temperatures are different resulting in losing the mechanical properties of one of the parent material.

In fusion welding, most of the listed problems occur in Heat Affected Zone (HAZ) and joint/weldment. This is due the fact that in fusion welding, as it is localized heating, weld and HAZ are heated and the rest of the part is not heated [5,6]. The intensity of problem related to heat treatment is more in brazing, particularly vacuum brazing as the whole part (of the component) is heated to the brazing temperature [7,9]. To avoid interference of brazing cycle to the heat treatment cycle of alloys, brazing and heat treatment cycles were made equal in this study [8, 9, 10, 11, 12].

Chemical composition and mechanical properties of the alloys used for the study are given in Table 1 and 2 respectively. Heat treatment (HT) procedure for the alloy is given in Table 3. From the literature, it is clear that the brazing temperature of CuCrZr alloy is 980°C, for PHSS, it is 1040° C. To carry out the brazing of these two alloys with different temperature, PHSS be heated to more temperature than CuCrZr which is the aim of this study.

Table 1a. Chemical composition of PHSS in Wt %

Element	Cr	Ni	Cu	Si, Mn, Nb, Mo	Fe
%	16.8	4.1	4.14	0-0.7	Rest

Table 1b. Chemical composition of CuCrZr alloy in Wt %

Element	Cr	Zr	Cu
%	0.8	0.05	Rest

Table 2a. Mechanical properties of PHSS in aged condition

Property	Y.S (MPa)	U.T.S (MPa)	% Elongation	Hardness (VHN)
Value	1170	1310	10	430

Table 2b. Mechanical properties of CuCrZr alloy in aged condition

Property	Y.S (MPa)	U.T.S (MPa)	% Elongation	Hardness (VHN)
Value	220	400	20	130

Table 3a. Heat treatment procedure of PHSS and strength after heat treatment

Treatment	Temperature	Cooling	U.T.S (MPa)
Solution Annealing	1040-1065° C	Gas quench	900
Aging	482 – 621°C	Air cool	1310

Table 3b. Heat treatment procedure of CuCrZr and strength after heat treatment

Treatment	Temperature	Cooling	U.T.S (MPa)
Solution Annealing	950-980° C	Gas quench	230
Aging	450 – 500°C	Air cool	400

Experimental Procedure

For brazing experiments, PHSS and CuCrZr alloy samples of 10 mm X 20 mm X 50 mm were used and butt joint was made out of that on 10 mm X 20 mm side. For components which are used in ITER, 15 mm ID and 25 mm OD pieces were used as shown in Fig 1.b. Samples were selected in solutionised condition. Gold-18% nickel alloy was used as brazing filler materials and the brazing parameters are listed in Table 4. Properties of brazing filler alloy are listed in Table 5. Samples were assembled with brazing alloy and loaded in high vacuum high temperature furnace (Thermal Technology Inc make). The schematic of the experimental assembly with tiny heater set up at PHSS side is shown in Fig. 1a.

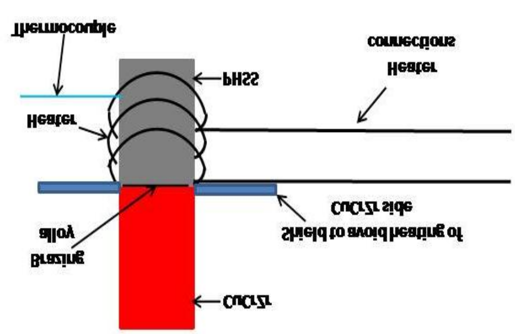

Fig. 1a. Schematic of experimental set up- with tiny heater

Fig. 1b. Components made for ITER based on this research study

After evacuation of the furnace to 1x10^{-4} m.bar, the assembly was heated to the brazing temperature (as per Table 4) at rate of 10 °C per minute and soaked for 30 minutes. During the same time, the special tiny heater in the assembly was on and the power was adjusted in such a way that the PHSS part is heated to 1040°C for a set of experiment, where the rest of the system including CuCrZr alloy was heated to 980°C. At end of the soaking time, ultra pureAr gas was introduced to the pressure of 1200 m.bar. Then it was quenched by forced circulation Ar gas. Brazing cycle followed for the experiment is shown in Fig 2. Cooling rate was as per cycle shown in the figure.

During brazing, a dummy samples (PHSS and CuCrZr) were loaded for every cycle to analyze the effect of brazing cycle (temperature) on the base material (Parent Material). This task was necessary as main aim of this research was studying the effect of brazing temperature on the properties of PHSS and CuCrZr and find a suitable brazing cycle. After brazing, all the samples including dummy samples were artificially aged at 496° C for 4 hours followed by air cooling.

Table 4. Brazing parameters

Brazing temperatures	*Time (Min)*	*Gas pressure for quenching*
980°C	30	1200 m.bar
980°C conventional	30	Furnace cooling
980°C- with tiny heater for 1040° C at PHSS part	30	1200 m.bar
1040 °C	30	1200 m.bar
1040°C- conventional	30	Furnace cooling

Table 5. Brazing alloy characteristics

Standard	Compo--sition	Melting point	Condition	thickness
Nioro/ AMS4787	Au:82% Ni: 18%	955°C	Annealed	50 micron

After aging treatment, test samples were prepared (from brazed samples and dummy samples) for tensile testing (determining joint strength and strength of base metal -PHSS and CuCrZr), joint microstructure and hardness. Tensile test samples were made as per AWS 3.1 with joint at the centre of gauge length. Tensile testing was carried out in 25 kN Shimadzu UTM. Cross head speed of tensile testing was 2 mm per minute. Tensile samples before and after tensile testing are shown in Fig. 3 and 4 respectively. Metallographic samples were prepared by standard sample preparation method by emery paper polishing followed by cloth polishing and etching. Micrographs were recorded using Olympus optical microscope. After recording the microstructures, same samples were used for hardness testing. Hardness testing was carried out using Shimadzu Vicker Hardness testing machine with load of 5 kg and indentation time of 10 seconds.

To compare the obtained results with the conventional brazing results, brazing trial was conducted at 980°C and 1040°C in same manner *without quenching*. Dummy samples were subjected to only tensile testing by same standards and the results were compared.

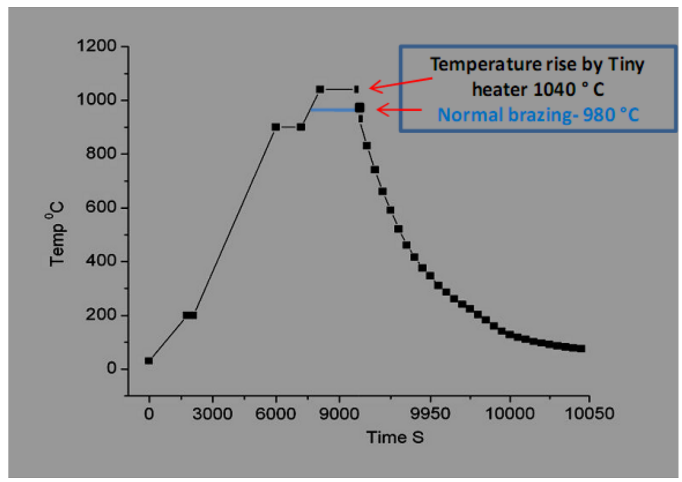

Fig 2. Brazing cycle (Brazing temperature: 1050° C, Quenching pressure: 1300 m.bar)

Results and Discussion

Joint strength:

Joint strength values are shown in Table 6 for all brazing parameters. From the results, it is evident that maximum value of joint strength was achieved for all brazing conditions. Moreover the parameter where from the proved results of the literature for conventional vacuum brazing [2, 7, 8, 9]. The joint strength was more than the weakest parent metal (CuCrZr alloy) of the system as the failure occurred on CuCrZr alloy part, away from the joint as shown in Fig. 4.

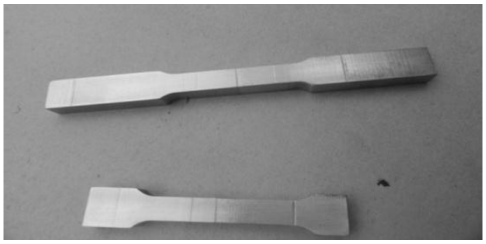

Fig 3. Tensile test samples

Fig. 4.Tensile test sample after testing.

Table 6. Joint strength and mechanical properties of PHSS and CuCrZr (parent metals) after brazing and aging

Brazing condition (°C)	Joint strength (MPa)*	Properties of CuCrZr		Properties of PHSS	
		St**	Ha***	St**	Ha***
980°C	Above 360	360	112	1012	321
980 °C, conventional	Above 310	280	102	960	301
980°C- with tiny heater at PHSS for 1040° C	Above 357	360	111	1190	366
1040 °C	Above 215	215	108	1220	369
1040 °C, conventional	Above 256	256	96	938	338

* The joint strength was more that the CuCuZr alloy, as the test piece failed NOT at joint as shown in Fig. 4.
** Strength , MPa
*** Harness, VHN

Mechanical properties of PHSS and CuCrZr:

Mechanical properties of PHSS and CuCrZr which underwent brazing cycles are listed in Table 6. Main aim of the research is to select the optimum brazing cycle/condition with respect to joint strength and mechanical properties of PHSS and CuCrZr alloy. Selected cycle should achieve the maximum properties of PHSS and CuCrZr alloy. From the results shown in Table 6, it is established that the brazing at 980°C with a tiny heater on PHSS side results in best properties of both PHSS and CuCrZr alloys. The strength dropped due to brazing cycle marginally (from the standard values as per table 2) for this parameter, whereas for conventional parameters (the brazing was conducted without quenching) and brazing without tiny heater set up, the drop in mechanical properties was considerable.

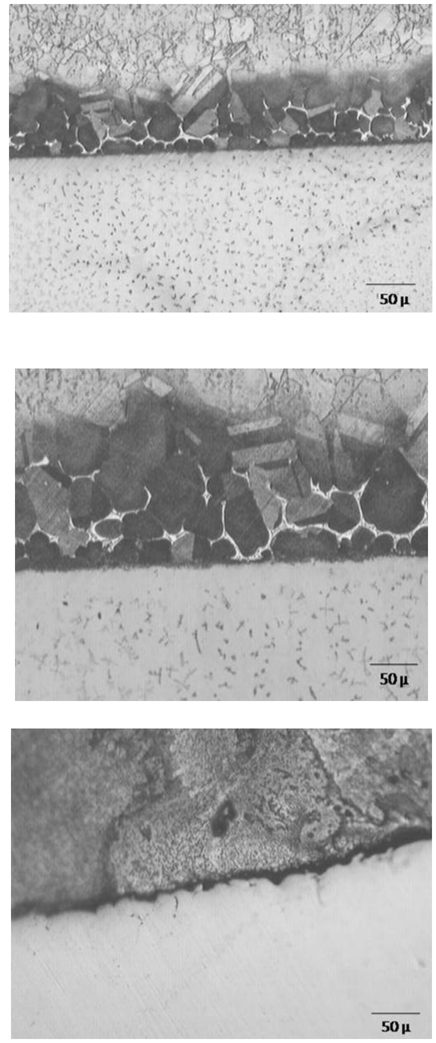

Fig 5. Microstructure of joint for various brazing temperatures: a) 980°C b) 980°C with tiny heater on PHSS part, c) 1040° C.

Joint microstructure:

Joint microstructure results are shown in Fig. 5. From the microstructure, it was confirmed that the joint is flawless and no porosity/unfilled gaps were observed. Dissolution/ flow/ alloying of the brazing filler material with parent material was good, which indicated completer wetting. The length of alloying on copper side was more which is as expected as per literature. Brazing temperature made considerable change in the microstructure of CuCrZr alloy and it was clearly visible. The grain growth was significant in CuCrZr alloy for the brazing temperature of 1040 °C, the microstructure was changed near the joint as well as in interiors. For 980 °C with heater on PHSS part, the grain growth was visible but still limited to the nearby area of joint as the temperature rise was limited on copper part. For 980 °C, the joint microstructure was metallurgically sound, but the properties of PHSS were not up to the mark.

Conclusions

1. A novel differential temperature vacuum brazing process coupled with heat treatment was proved for dissimilar joining of heat treatable alloys.
2. UNS17400PHSS was vacuum brazed with UNS18500CuCrZr alloy in concurrence with its heat treatment cycle, and the joint strength better than the CuCrZr alloy (weaker alloy) part for all the selected parameters.
3. Mechanical properties of PHSS and CuCrZr alloys were maximum for brazing temperature 980°C with a tiny heart for PHSS part to heat 1040 °C.

Acknowledgments

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