Microstructural evolution of brazing 422 stainless steel using the BNi-3 braze alloy

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The 422 stainless steel (422SS) is one of the typical martensitic stainless steels with both excellent creep strength and corrosion resistance up to 650°C. Its application includes steam turbine blades, high temperatures bolting... etc. Repair welding of 422SS is one of the most common methods to fix the turbine blade. However, repair brazing of surface shallow cracks, e.g., less than 1 mm in depth, is an alternative way to fix such blades. The microstructural evolution of brazing 422SS with BNi-3 braze alloy using both infrared and furnace brazing was performed in the study. Based on the experimental results, BNi-3 cannot effectively wet 422SS substrate below 1025°C. As the brazing temperature increases above 1050°C, comprehensive wetting can be obtained in 1200 sec. For the infrared brazed specimen with a short brazing time, the cooling path starts from the formation of a BNi3 phase in the molten braze, subsequently forms a Ni-rich phase, and finally a eutectic phase is solidified from the residual eutectic liquid. The microstructure of the furnace-brazed specimen is similar to that of infrared brazed specimen, but the interfacial reaction zone is significantly increased in furnace brazing. There are Kirkendall voids in the braze close to the interface between BNi-3 and 422SS, and the size of Kirkendall porosity is increased with increment of the brazing time and/or temperature. The homogenization treatment of the brazed joint at 900°C results in growth of both the interfacial reaction zone and porosity.

1. Introduction
The importance of martensitic stainless steels is increasing in recent years due to the demand from power generation industry [1–3]. Its successful application in corrosive and/or high temperature environment, e.g., high temperature steam pipes, steam turbine blades, rotors... etc., has been widely reported in the literatures [1, 4–6]. The 422 stainless steel (422SS) is one of the representative martensitic stainless steel. It is designed for service temperatures up to 650°C, and resistance to oxidation and scaling is good in continuous service at temperature up to 760°C [7]. Excellent mechanical properties can be developed with proper heat treatment of the 422SS [7]. Therefore, it is an excellent alloy characterized with both good creep strength and corrosion resistance. Applications of the 422SS include buckets and blades in compressors and steam turbines, high temperature bolting, compressor and turbine wheel, valves and valve trim, and aircraft parts [7]. Therefore, many researchers have focused on the mechanical properties, fatigue resistance, and corrosion resistance of the 422SS [8–14].

Both the high-pressure and intermediate-pressure steam turbine blades in fossil power plant are primarily made of the 422SS. The carbon content of this alloy is high, and it is alloyed with many other elements, such as Cr, Mo, V... etc., resulting in high hardenability of the steel. Therefore, the 422SS is difficult to weld due to crack sensitivity [7]. Some studies have been established in welding and/or repair welding of the 422SS [9, 10, 15–18]. Repair welding of 422SS is one of the most common methods to fix such turbine blades. However, the repair welding of shallow cracks on the tips of turbine blades is not the only choice. Repair brazing of surface shallow cracks, e.g., less than 1 mm in depth, is an alternative way to fix the blades. Therefore, both processes are complementary to each other.

Brazing produces coalescence of materials by heating them to the brazing temperature in the presence of a filler metal having a liquidus above 450°C and below the solidus of base metal [19–21]. This study proposes repair brazing of 422 stainless steels, and two primary repair brazing technology will be developed including traditional furnace brazing and infrared brazing. Infrared brazing utilizes infrared energy generated by heating a tungsten filament in a quartz tube as the heating source, and it is featured with a very fast heating rate up to 3000°C/min [22–24]. The infrared rays can

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transmit through the quartz tube, and not be absorbed by the furnace itself. Consequently, local heating of the bonding surfaces can be acquired by using an appropriate optical focusing system. Infrared brazing is a very promising technology among all brazing processes [22–24].

Nickel base braze alloys are featured with good corrosion resistance and creep strength, so they are good choices in repair brazing of 422SS. BNi-3 is a nickel base braze alloy, and its chemical composition in weight percent is 3.1 B, 4.5 Si, 0.06 C (max) and Ni balance. The solidus temperature of BNi-3 is 980 °C, and its liquidus temperature is 1040 °C [19]. The brazing temperature of BNi-3 braze is between 1010 °C and 1175 °C, and the suggested brazing temperature of BNi-3 alloy is 1040 °C [19]. The range of 422SS austenitizing temperature is between 1040 °C and 1055 °C, so it is preferred that the repair brazing temperature of 422SS is below 1055 °C [7]. Accordingly, the suggested brazing temperature of BNi-3 is very close to the austenitizing temperature of 422SS. Therefore, BN-3 was chosen as the brazing filler metal in the study.

The purpose of this investigation is concentrated on the repair brazing of 422SS using both infrared brazing and furnace brazing. A nickel base braze alloy, BNi-3, was used as brazing filler metal. The effect of process variables, e.g., brazing temperature, brazing time and homogenization time etc., on the microstructural evolution of the brazed joint will be extensively evaluated.

2. Experimental procedure

The base metal used in the experiment was 422SS disk with the diameter of 32 mm and thickness of 3 mm. Its chemical composition in weight percent was 0.24 C, 0.71 Mn, 0.38 Si, 0.016 P, 0.006 S, 0.76 Ni, 11.98 Cr, 1.07 Mo, 0.26 V, 0.99 W and balance Fe. The 422SS specimen was polished by using a SiC paper, and an ultrasonic bath made use of acetone as the solvent to clean the specimen prior to brazing. A nickel base filler metal, Nicrobraz 130 made by Wall Colmonoy Co., was chosen as the braze alloy in the experiment. According to the specification of American Welding Society (AWS) for Ni base braze alloys, the chemical composition of Nicrobraz 130 alloy is consistent with BNi-3 braze [19]. The braze alloy was in the form of Nicrobraz 130 tape with the thickness of 125 μm and 50 mm wide.

Infrared brazing was performed in a vacuum of 5 × 10⁻⁵ mbar at temperatures between 1050 °C and 1100 °C for various time periods. The heating rate of furnace brazing was set at 30 °C/min throughout the experiment. All specimens were preheated at 600 °C for 600 sec prior to the brazing temperature. Traditional furnace brazing was performed in a vacuum of 5 × 10⁻⁵ mbar at temperatures between 1050 °C and 1100 °C for various time periods. The heating rate of furnace brazing was set at 30 °C/min throughout the experiment. All specimens were preheated at 600 °C for 600 sec prior to the brazing temperature. In order to study the microstructural evolution of the brazed joint, the furnace brazed specimen was subsequently homogenized at 900 °C for 24 and 120 hrs, respectively. The process variables applied in brazing 422SS using BNi-3 (Nicrobraz 130) filler metal are summarized in Table I.

Dynamic wetting angle measurements were made using the above traditional furnace at the temperature ranges between 1025 °C and 1100 °C for 0–1800 sec [25, 26]. 0.15 g master alloy was placed on the 422SS substrate, and the heating rate of the furnace was 30 °C/min. The image of wetting angle was recorded simultaneously by a camera.

The brazed specimen was cut by a low speed diamond saw, and the specimen subsequently experienced a standard metallographic procedure prior to further inspection. The etching solution used in the experiment was the solution of 50% acetic acid and 50% nitric acid. The cross section of the brazed specimens was firstly examined by using a Hitachi 3500 H scanning electron microscope (SEM) with an accelerating voltage of 15 KV. Quantitative chemical analysis was performed using a JEOL JXL-8800 M electron probe microanalyzer (EPMA) with an operation voltage of 15 KV and spot size of 1 μm.

3. Results and discussions

Fig. 1 shows the dynamic wetting angle measurement of BNi-3 braze on 422SS for 1025–1100°C between 0–1800 sec. Based on the figure, BNi-3 cannot effectively wet 422SS substrate below 1025°C.