Effect of Gap Filler and Clearance of Gap on Microstructure of Wide-gap Brazing Seam

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The influence of gap filler content, gap filler powder size and clearance of gap on the microstructure of the brazing seam was investigated. The volume fraction of the eutectic plus the intermetallic compound and the number of voids in the brazing seam were used to evaluate the factor. The results show that the content of gap filler affects the microstructure of the brazing seam greatly, while the gap filler powder size and the clearance of the gap have little effect on it.

KEY WORDS: brazing; wide-gap brazing; microstructure.

1. Introduction

High-temperature brazing, which has been widely used in industry, has been demonstrated to be able to produce high-performance joints.\textsuperscript{1,2)} In order to obtain good performance joints, the joints to be brazed are required to have a capillary clearance from 0–0.15 mm for conventional brazing.\textsuperscript{1)} However, sometimes it is difficult to maintain this clearance due to machining and assembly errors, and therefore, the wide-gap brazing is often used.\textsuperscript{3–9)} Unlike in conventional brazing, the braze filler is often a mixture of filler metal and a high temperature melting powder in wide gap brazing, the latter being more commonly referred to as the gap filler. During brazing, the gap filler particles remain largely unmelted, thus providing the necessary capillary force to retain the molten filler metal which would otherwise be too fluid to bridge the gap faying surfaces. The filler metals used in high-temperature brazing often contain melting-point depressants such as B, Si and P which form eutectic structure and intermetallic compound detrimental to the heat-resistance of the brazing seam.

Although many researches\textsuperscript{1,7–9,10)} have been done to investigate the effects of materials and process parameters on the microstructure of the brazing seam, these researches are not systematic and more work is needed to control the microstructure of the brazing seam so as to improve the heat-resistance of the brazing seam.

In this paper, effect of three factors (the content, the size of gap filler and the clearance of gap) on the brazing seam was investigated. Volume fraction of the eutectic plus the intermetallic compound and the number of the voids in the brazing seam, which were the two most important factors affecting the heat-resistance of the brazing seam, were used as a standard to measure the effect.

2. Experiment

For brazing, nickel-based superalloy K3 was used as the base metal, and N300 was selected as the filler metal while Rene ‘95 powder was chosen as the gap filler. Table 1 shows the chemical compositions of the materials used in the experiment. The gap to be brazed was machined, ground, cleaned and then agitated for about 20 min in a bath of acetone on an ultrasonic cleaner. Mixture of gap filler and filler metal was placed in the gap while the filler metal was placed in the reservoir area outside the gap as shown in Fig. 1. Brazing was carried out in a furnace at 1 180°C in a vacuum of above $2 \times 10^{-2}$ par for 15 min, and then cooled to room temperature.

Three factors (content (A) of gap filler in the mixture, clearance (B) of gap and size (C) of gap filler) were considered and each factor was tested at three levels. If 3\textsuperscript{3} design was carried out, there would be 27 runs. So much runs would be labor and time-consuming, so we executed or-

| Table 1. Chemical compositions and state of materials used in the study. |
|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|
|                 | chemical compositions, w% |                 |                 |                 |                 |                 |
|                 | Cr    | Co    | W    | Mo    | Nb    | Al    | Ti    | B    | Zr    | C    | Ni    | Si    | Fe    | state |
| K3              | 11    | 5.2   | 5.2  | 4.2   | 5.5   | 2.6   | 0.017 | 0.05 | 0.14 | bal. | –     | –     | –     | plate bar |
| Rene ‘95        | 14    | 8     | 3.5  | 3.3   | 3.5   | 3.5   | 2.5   | 0.01 | 0.05 | 0.15 | bal. | –     | –     | powder |
| N300            | 25 bal.| 10    | –    | –    | –    | 3.0   | 0.75  | 17   | 2.75 | 2.0  | –     | –     | –     | powder |

Fig. 1. Wide-gap brazing joint.
thogonal designs. Table 2 gives the orthogonal array. Each level of every factor appeared in three runs and each level of one factor only met each level of other factors once, so that fewest runs were carried out to realize balanced design.11)

After brazing, the brazed joints were sectioned depthwise across the gap into two equal halves. They were ground progressively using silicon carbide paper, polished with diamond pastes, and then etched with a mixture of HF:C,H,OH:H,OH=1:10:85. Optical microscope was used to observe the microstructure, measure the volume fraction of the eutectic plus the intermetallic compound in the brazing seam and obtain the number of the voids.

3. Results

Figure 2 shows the microstructure of the wide-gap brazing joint. A indicates the base metal while B indicates the brazing seam. Table 3 gives the volume fraction of the eutectic plus the intermetallic compound and the number of the voids in the brazing seam.

There were three levels of content, size of gap filler and clearance of gap respectively, each level of the factors appeared in three runs. In order to analyze the effect of these factors on the eutectic, the intermetallic compound and the voids, each level for each factor should be considered generally. For example, the level of 20% gap filler appeared in No. 1, No. 2 and No. 3 runs. The average volume fraction of the eutectic plus the intermetallic compound was $f_1=(34.4+35.6+33.7)/3 \times 100\% = 34.6\%$. In this way, we got the result in Table 4. The maximum difference could be obtained as follows: for every factor, maximum difference = maximum yields - minimum yields. For example, as to factor A, the yields was the maximum (34.6%) at the level of 20%, and the yields was the minimum (1.3%) at the level of 60%, then the maximum difference was 33.3%.

As can be seen in Table 4, the factor that affects the microstructure of the brazing seam most greatly is the content of the gap filler in the mixture. With the increase of the gap filler, the amount of the eutectic and the intermetallic compound decreases sharply. When the content of the gap filler is little, there are few voids in the brazing seam. When the gap filler amounts to 60%, many voids appear in the brazing seam. Some area of the brazing seam can’t be brazed. When the content of the gap filler is suitable (~40%), the microstructure of the brazing seam is the best. The size of the gap filler and the clearance of the gap have little effect on the microstructure.
4. Discussion

When the content of the gap filler in the mixture is little, during the process of brazing, small amount of solid gap filler is surrounded by large amount of liquid filler metal. In a short time, solid gap filler solves somewhat and the brazing seam somewhat alloying reacts. During cooling after brazing, the fluid filler metal (as the composition of the filler metal is near eutectic) could fill every part of the brazing seam, therefore there is no such defects as voids, but there are a large amount of eutectic and intermetallic compound. With the increase of the content of the gap filler, the volume fraction of the filler metal in the mixture decreases, so the eutectic and the intermetallic compound become less. At the same time, the solution of gap filler in the liquid filler metal increases the melting point and decreases the fluidity of the latter one. So that the brazing seam can’t be filled completely, when the content of the gap filler is too large, the poor fluidity in addition to the too little amount of filler metal results in a great number of voids and some area of the brazing seam can’t be brazed.

So, when suitable amount of gap filler (~40%) and the filler metal are mixed properly the brazing seam consists of particles of gap filler with some solid solution and small bulky boride and little amount of eutectic, there is no obvious voids. These results are in accordance with the pervious studies.10)

As to the wide gap brazing, adding gap filler makes the brazing seam have good capillary force. So the existence of gap filler eliminates the effect of clearance on the weldability and the microstructure of the brazing seam. Similarly, the gap filler and the filler metal are placed together in the brazing seam mixedly, the size of the gap filler powder has little effect on the weldability of the brazing seam if only the two components are mixed homogeneously.

5. Conclusion

The most important parameter in wide gap brazing with the mixture of gap filler and filler metal is the content of gap filler in the mixture. Too little amount of gap filler leads to massive eutectic and inermetallic compound in the brazing seam, while too large amount of gap filler leads to many voids in the brazing seam. When suitable content of gap filler (~40%) is mixed homogeneously with the filler metal, the microstructure of the brazing seam is the best in this experiment.

The size of the gap filler powder and clearance of gap have little effect on the microstructure of the brazing seam.

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