# THE INFLUENCE OF HIGH-TEMPERATURE BRAZING UPON INDICATORS OF MATERIAL BRAZEABILITY

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***Abstract***

*The effect of both common and extreme parameters of AISI 321stainless steel high-temperature brazing using the NI 102 brazing alloy upon material brazeability indicators. The ascertainment of the wetting angle, the area over which Ni brazing alloy spreads, the width of AISI 321 steel's dissolubility band, and the width of Ni brazing alloy's diffusion band into the basic material.*

***Keywords:*** *High-temperature brazing, stainless steel AISI 321, nickel brazing alloys, wettability, fluidity, dissolubility, diffusion.*

## 1. Introduction

Thin-walled parts, especially pipes made from austenitic stainless steels are heretofore commonly brazed using hard silver solders and borax based flux. Brazed joints have good mechanical properties, but this is only true for operating temperatures less than 250 °C [1].

If there is a requirement for higher operating temperatures (above 500 °C), it is necessary that high-temperature vacuum brazing be chosen at a brazing temperature of over 950 °C.

Nickel-based brazing alloys are the most convenient materials for high-temperature brazing of austenitic stainless steels. For parts made form stainless steel and joined using high-temperature nickel-based brazing alloy, the resulting metallurgical joint has properties similar to those of a welded joint. Unlike in welding, however, the melting of the basic material (BM) will not occur due to a lower brazing temperature.

The research was aimed at ascertaining the effect of both common and extreme parameters of AISI 321 stainless steel high-temperature brazing using the NI 102 brazing alloy upon material brazeability indicators such as wettability, fluidity, dissolubility (erosion), and diffusion.

## 2. Experimental Program

The experiments were aimed at ascertaining the effect of austenitic stainless steel high-temperature brazing parameters upon material brazeability indicators. The material brazeability indicators to be ascertained included:

- The fluidity of Ni brazing alloy on AISI 321 stainless steel surface,
- The wettability of Ni brazing alloy,
- The dissolubility (erosion) of AISI 321 stainless steel in Ni brazing alloy, and
- The width of Ni brazing alloy's diffusion band into the AISI 321 basic material.

### *2.1 Experimental Samples*

The fluidity and wettability was ascertained by examining sheet metal samples with dimensions of 40 x 40 millimeters and 2 mm in thickness, using 1 gram of brazing alloy in the form of powder. The wettability sample – *Fig. 1* – was cut into halves, then a metallographic specimen was prepared to measure the wetting contact angle $\alpha$ *and to measure the transition areas (dissolubility band and diffusion band) and their micro-hardness.*

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*Fig. 1. Sample of fluidity of highly alloyed austenitic steel with Ni brazing alloy*

The dissolubility of BM's contact surface in liquid brazing alloy was ascertained by examining samples as per Fig. 2 through the measurement of an opening of $\varnothing_1 = \pm$ 0,001 mm prior to brazing and, after brazing, the measurement of $\varnothing_2$ in the surface (A-A section) cut and polished for metallographic analysis.

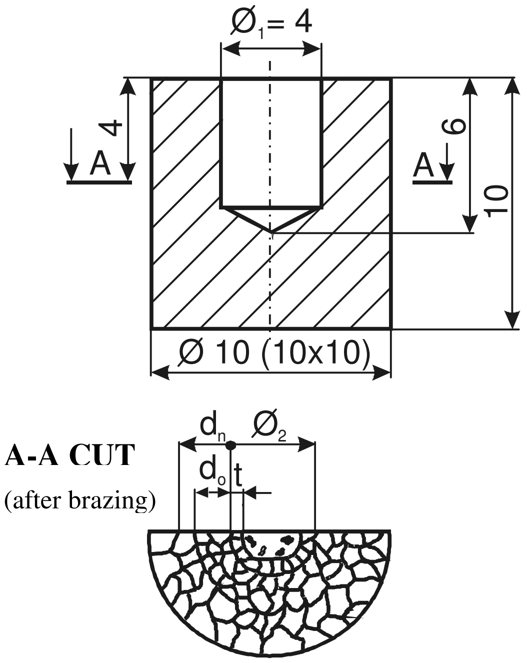


*Fig. 2. Sample taken for the purposes of ascertaining the degree of BM's dissolubility (erosion) in Ni brazing alloy*

***t** – dissolubility band width, $\boldsymbol{d_o}$ – diffusion of brazing alloy's elements in grains, $\boldsymbol{d_n}$ – diffusion of brazing alloy's elements over grain edges [2]*

### *2.2 Experimental Material*

For the purposes of these experiments, the AISI 321austenitic stainless steel was selected (X6CrNiTi 18-10) – Table 1.

*Tab. 1*

*Chemical composition of AISI 321 steel – mass percentage*

| Fe | Cr | Ni | Mn | Si | C | W | Ti | Mo |
|---|---|---|---|---|---|---|---|---|
| 67.00 | 19.30 | 8.12 | 1.27 | 0.41 | 0.02 | 0.63 | 0.36 | 0.06 |

Out of a whole range of high-temperature nickel-based brazing alloys, two alloys were selected with similar chemical compositions. The brazing alloys had been prepared by adding an interstitial element – boron (3 mass % in one case, 2 mass % in the other case – see Tab. 2). Pursuant to the STN EN 1044 standard, both of the alloys can be designated as NI 102.

*Tab. 2*

*Chemical composition, mass percentage*

| Brazing Alloy | Ni | Cr | Si | B | C | Fe |
|---|---|---|---|---|---|---|
| NI 102 (01) | 83.5 | 6.5 | 4.5 | 3.0 | 0.05 | 4.0 |
| NI 102 (02) | 82.0 | 7.0 | 4.0 | 2.0 | 0.15 | 4.5 |

### *2.3 Brazing Parameters and Conditions*

The samples were made in PZ 810 vacuum furnace providing a heating speed of 26.88 °C/min and a cooling speed of 2.15 °C/min, under a vacuum of $10^{-2}$ Pa. The brazing temperatures were selected within a wide range of common and extreme brazing conditions. The specific parameters are shown below for each sample examined.

## 3. Experiments' Results

### *3.1 Material Brazeability Indicators*

Figure 3 shows graphical representation of the results regarding the NI 102 (01) brazing alloy's spreadability *R* ($mm^2$) in dependence on brazing conditions.

The results presented on Fig. 3 indicate that the brazing temperature's effect upon brazing alloy's spreadability is smaller than that of dwell time.

Generally, it can be concluded that the spreadability increases with increasing brazing temperature and dwell time.

The results regarding the brazing alloy's spreadability are also linked to further brazing stages, particularly the diffusion of brazing alloy's elements into basic material's contact surface as well as to the intensity of the contact surface's dissolution in liquid brazing alloy. These brazing stages have an effect upon the creation of a solid solution zone (t) in the

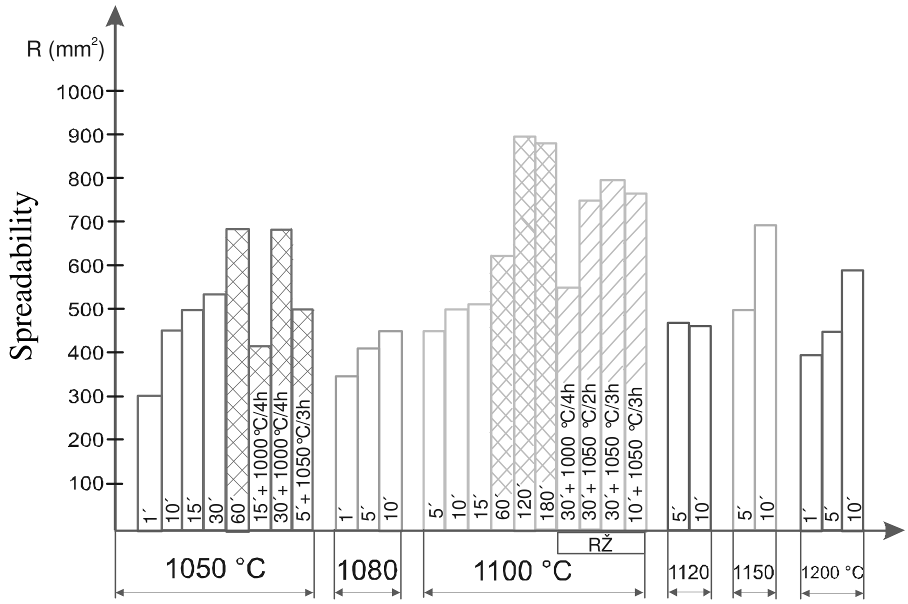


*Fig. 3. The results regarding the NI 102 (01) brazing alloy's spreadability R (mm²) in dependence on brazing conditions*

contact surface. Since the wetting and creep of brazing alloy is interlinked with the diffusion, this process is irreversible.

To examine **wettability**, samples were selected made under the parameters shown in Tab. 3. The wetting contact angle $\alpha$ was determined from photographs taken through an optical microscope, using a graphical application.

*Tab. 3*

*Brazing parameters for purposes of examining wettability.*

| Brazing Alloy | Brazing Temperature [°C] | Dwell Time at Temperature [min.] |
|---|---|---|
| **Sample 1** | | |
| NI 102 (01) | 1200 | 10 |
| NI 102 (02) | 1200 | 10 |
| **Sample 2** | | |
| NI 102 (01) | 1050 | 30 |
| NI 102 (02) | 1050 | 30 |
| **Sample 3** | | |
| NI 102 (01) | 1100 | 120 |
| NI 102 (02) | 1050 | 120 |

An example of the measurements can be seen on figures 4, 5, and 6 where you also can observe the change in the contact angle due to the influence of different parameters. The measurement results are included in Tab. 4.

Tangent to BM surface - $\sigma_{SL}$

Tangent to brazing alloy surface -

Wetting angle - $\alpha$

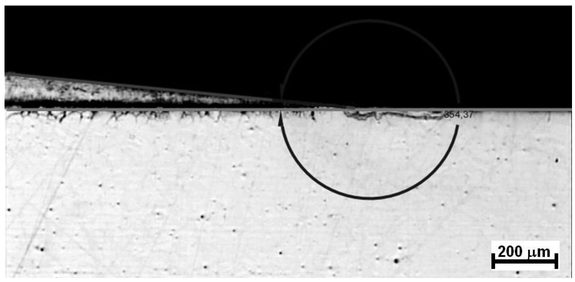


*Fig. 4. NI 102 (02), α ~ 2.34° (1200 °C/ 10 min.)*

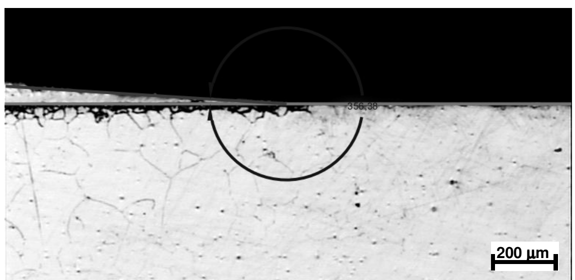


*Fig. 5. NI 102 (02), α ~ 5.14° (1050 °C/ 30 min.)*

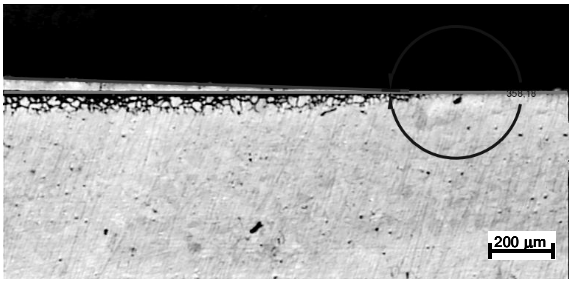


*Fig. 6. NI 102 (02), α ~ 1.5° (1050 °C/ 120 min.)*

*Tab. 4*
*Wetting angle values of the brazing alloys examined under given parameters*

| Brazing Alloy | Dwell Time at Brazing Temperature [min.] | Brazing Temperature [°C] | Wetting Angle [°] |
|---|---|---|---|
| **NI 102 (01)** | 10 | 1200 | 1.54 |
| **NI 102 (02)** | 10 | 1200 | 2.34 |
| **NI 102 (01)** | 30 | 1050 | 3.4 |
| **NI 102 (02)** | 30 | 1050 | 5.14 |
| **NI 102 (01)** | 120 | 1100 | 1.45 |
| **NI 102 (02)** | 120 | 1050 | 1.5 |

Based on the measured wettability values shown in Tab. 4, the following conclusions can be drawn:

- The wettability of both brazing alloys is excellent or even perfect for all parameters.
- A better wettability shown by the NI 102 (01) brazing alloy is probably caused by an increased boron content.

It was found through experimental measurement that the higher is the brazing temperature the greater is the **dissolubility intensity** of BM's contact surface, depending on the type of brazing alloy used – NI 102 (01) or NI 102 (02) – Fig. 7.

The pictures below show examples of photographs from which the diffusion band width of Ni brazing alloy into the AISI 321 basic material was ascertained. Figs. 8, 9 and 10 clearly display the increase in the diffusion band width under the influence of increasing parameters (brazing temperature and dwell time).

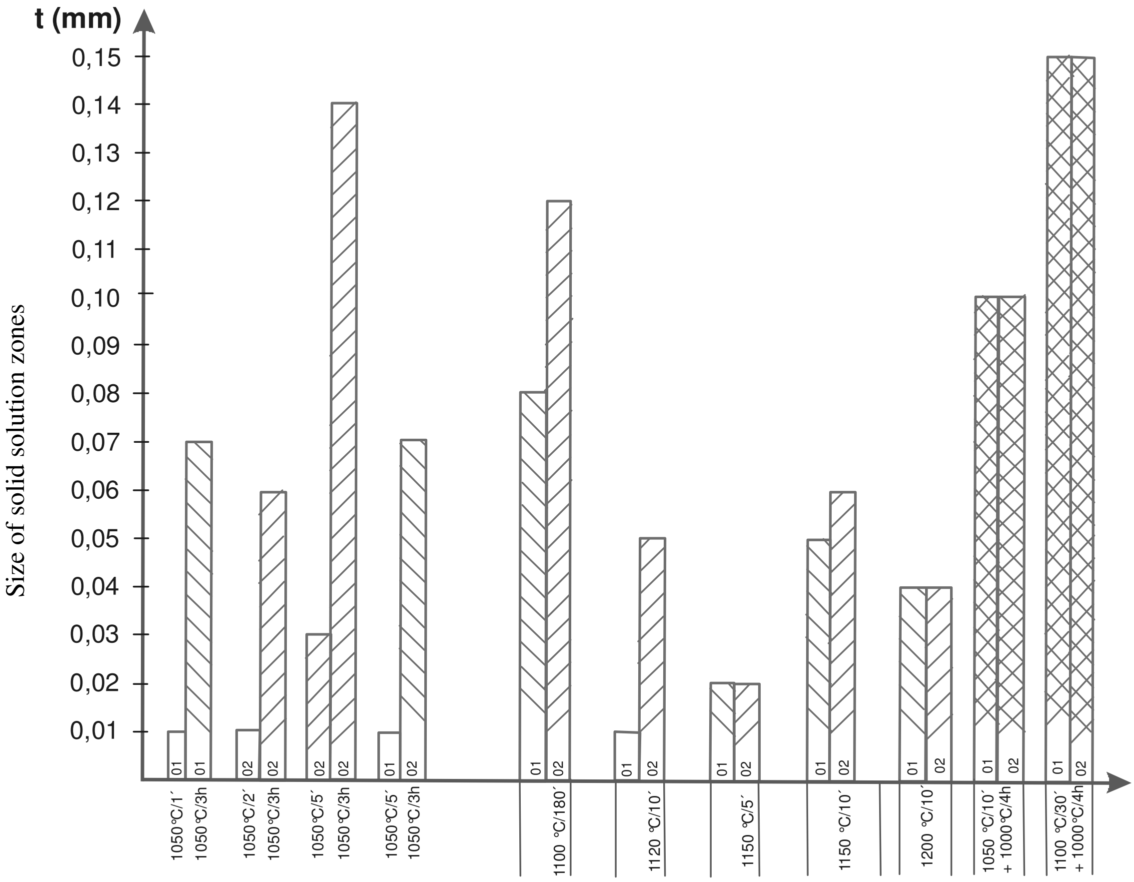


*Fig. 7. The size of solid solution zones (t) for NI 102 (01) and NI 102 (02) brazing alloys in dependence on brazing conditions*

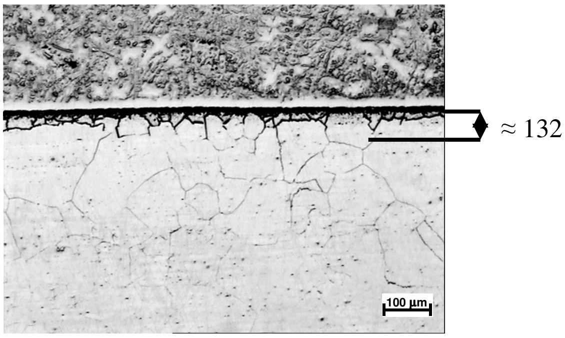


*Fig. 8. The width of NI 102 (02) brazing alloy's diffusion into AISI 321 (1200 °C / 10 min.) [µm]*

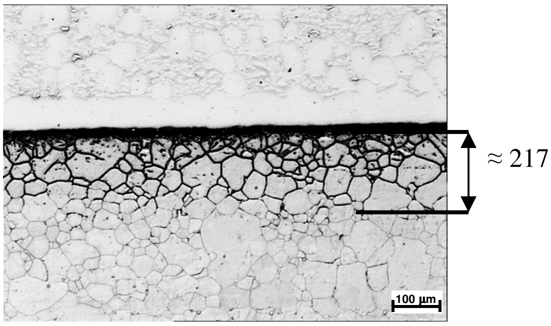


*Fig. 9. The width of NI 102 (02) brazing alloy's diffusion into AISI 321 (1050 °C / 30 min.) [µm]*

At the brazing parameters of 1100 °C/120 min., the width of brazing alloy's diffusion into BM approximately doubled and, at the same time, the diffusion was very complex (both in terms of volume and over grains' edges) – Fig. 10. The related measurement results are shown in Tab. 5.

*Tab. 5*

*Diffusion bands values as measured in dependence on brazing parameters*

| Brazing Alloy | Brazing Temperature [°C] | Dwell Time at Brazing Temperature [min.] | Diffusion Band Width [µm] |
|---|---|---|---|
| NI 102 (01) | 1200 | 10 | 116 |
| NI 102 (02) | 1200 | 10 | 132 |
| NI 102 (01) | 1050 | 30 | 126 |
| NI 102 (02) | 1050 | 30 | 217 |
| NI 102 (01) | 1100 | 120 | 276 |
| NI 102 (02) | 1050 | 120 | 369 |

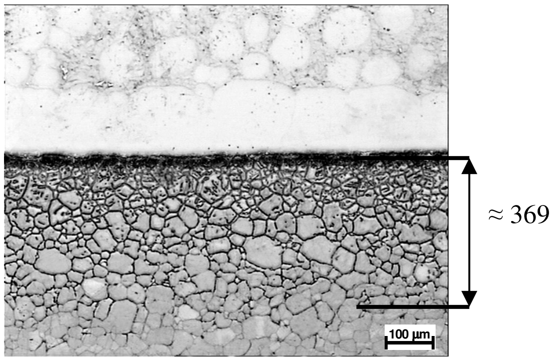


*Fig. 10. The width of NI 102 (02) brazing alloy's diffusion into AISI 321 (1050 °C / 120 min.)[µm]*

Based on the measured diffusion band values shown in Tab. 5, the following conclusions can be drawn:

- At the same brazing parameters, the NI 102 (02) brazing alloy displayed a deeper diffusion into BM and, vice versa, a better dissolubility was observed for the AISI 321 steel in the NI 102 (01) alloy.
- The influence of brazing temperature upon diffusion depth is about the same as the influence of the dwell at brazing temperature, with the effect of both parameters being directly proportional.

## 4. Conclusion

At all brazing parameters, the NI 102 brazing alloys on the AISI 321 stainless steel displayed very good wettability and fluidity for a wide range of brazing temperatures and dwell periods. It was found that the wetting angle decreases with the increasing brazing temperature as well as with the increasing dwell time at that temperature. The fluidity results indicate that the brazing temperature's influence upon brazing alloy's fluidity is smaller than that of the length of dwell time. It was also found that a slightly increased boron content (1,0 %) in the NI 102 (01) brazing alloy, as compared to NI 102 (02), resulted in a better wettability of AISI 321 surface.

It was found through experimental measurement that the higher is the brazing temperature the greater is the dissolubility intensity of the basic material's contact surface, depending on the type of brazing alloy used. At some brazing parameters, the brazing alloy with the composition of NI 102 (02) displayed a substantially greater dissolubility than the brazing alloy with the composition of NI 102 (01).

It was found through diffusion band measurement that the influence of brazing temperature upon diffusion depth is about the same as the influence of the dwell at brazing temperature, with the effect of both parameters being directly proportional.

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