Calculating Joint Clearance at Brazing Temperature

A simple analytical methodology is offered to evaluate and troubleshoot thermal expansion effects on brazing processes

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Many industrial fabrication procedures require joining dissimilar base materials, and brazing can be a suitable joining process for most of them. However, brazing process design for joining dissimilar materials requires some caution to prevent defective joints, as indicated — Fig. 1. The mismatch of thermal expansion coefficients between the base materials is commonly cited as the main source of residual stresses and dimensional distortions on the brazed joints (Ref. 1), and may even cause incomplete joint penetration due to an inadequate joint clearance at brazing temperature.

This article presents a simple analytical methodology to predict joint clearance at brazing temperature and indicates the most relevant parameters to be considered when designing a brazed joint with dissimilar base materials.

Joint Geometry Considerations

The joint clearance at brazing temperature can be evaluated with a simple model for thermal expansion of base materials. Due to the fundamental characteristic of thermal expansion, any joint configuration can be evaluated if the correct geometric relationships for the joint cross section are applied.

Intending to achieve the most comprehensive and applicable model, a joint constituted of two coaxial pipes with different diameters is considered, as sketched — Fig. 2A. The cross section of the joint is shown in Fig. 2B, where the joint clearance is highlighted.

As presented in Fig. 2B, the joint clearance for the selected geometry is given by the difference between the internal radius of external pipe *Re* and the external radius of internal pipe *Ri* for a concentric assembly.

Thermal Expansion Model

The two-dimensional (2D) thermal expansion evaluation for a pipe ensemble cross section is similar to that applied to holed surfaces (Ref. 2), which is schematically presented in Fig. 3.

As shown in Fig. 3, the hole expands as the temperature increases in the same way as the base material. Thus, evaluation of thermal expansion can be applied to the joint cross section to calculate *Re* and *Ri* dimensions at brazing temperature. Equation 1 presents the two-dimensional (2D) thermal expansion evaluation for a general joint cross section, which leads to Equation 2 for the circular area profile of a pipe ensemble.

1. Thermal expansion of surfaces:

$$A_1 = A_0 \cdot (1 + 2 \cdot \alpha_n \cdot \Delta T) \qquad (1)$$

where A_j is the area at the state *j*, with 0 and 1 denoting the initial and final states, respectively; α_n is the linear thermal expansion coefficient of base material *n*, with *e* and *i* denoting the external and internal materials; and ΔT is the temperature change.

2. Thermal expansion for circular profiles:

$$R_1^2 = R_0^2 \cdot (1 + 2 \cdot \alpha_n \cdot \Delta T) \qquad (2)$$

where R_j is the radius at the state *j* with 0 and 1 denoting the initial and final states, respectively.

The joint clearance (L) at brazing temperature can be evaluated as follows in Equations 3–5 by the calculation of *Re* and *Ri* dimensions at brazing temperature.

3. Joint clearance at room temperature:

$$L_0 = Re_0 - Ri_0 \qquad (3)$$

4. Joint clearance at brazing temperature:

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$$L_1 = Re_1 - Ri_1 \qquad (4)$$

5. Combining with the results obtained on Equation 2:

$$L_1 = (Re_0^2 \cdot (1 + 2\alpha_e \cdot \Delta T))^{0.5} - (Ri_0^2 \cdot (1 + 2\alpha_i \cdot \Delta T))^{0.5} \qquad (5)$$

where L_1 is the joint clearance at brazing temperature, and Rn_0 is the room temperature radius at the state *n*, with *i* and *e* denoting internal and external radii, respectively.

Therefore, the joint clearance at brazing temperature can be easily calculated, and the capillary conditions for correct joint penetration can be evaluated prior to the process.

Verifying Brazeability of Specific Steel Joints

The applicability of a brazing filler material for a specific brazing configuration is defined by a number of factors, such as chemical compatibility with the base materials and overall costs. Among these factors, the joint clearance dimension at brazing temperature and its tolerance must be carefully considered due to its impact on the base material preparation costs and their adequacy to the designed brazing process.

Table 1 presents the recommended joint clearance for the most common brazing filler metals applied for stainless steels brazing according to specialized literature.

Notice that Table 1 refers to joint

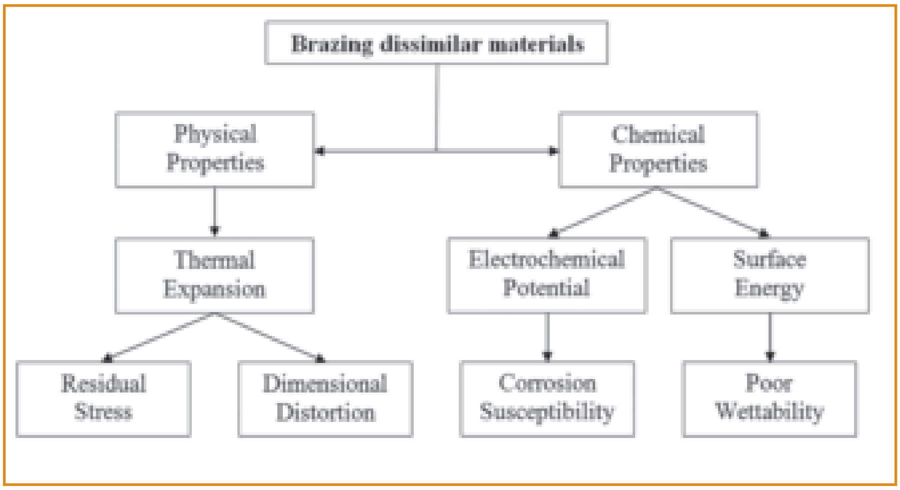

Fig. 1 — Relevant aspects to be considered on the design of brazed joints involving dissimilar base materials.

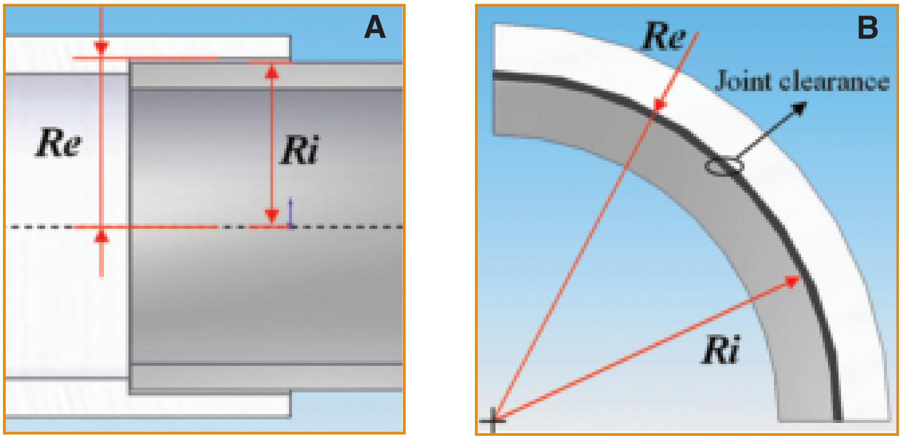

Fig. 2 — A — Pipe ensemble setup; B — detail of joint cross section.

Table 1 — Some Examples from Specialized Literature for Joint Clearance at Brazing Temperature (Refs. 3, 4)

Filler Metal AWS Classification	Brazing Temperature Range (°C) (°F)	Minimum Joint Clearance (μm) (in.)	Maximum Joint Clearance (μm) (in.)	Observations
BAlSi-2	599–621 (1100–1150)	0.00 (0.000)	50.8 (0.002)	Furnace brazing in vacuum
BCuP-1	788–927 (1450–1700)	25.4 (0.001)	127.0 (0.005)	Joint length under 1 in.
BAg-1	618–760 (1145–1400)	0.00 (0.000)	50.8 (0.002)	Atmosphere brazing
BAu-1	1016–1093 (1860–2000)	0.00 (0.000)	50.8 (0.002)	Atmosphere brazing
BCu-1	1093–1149 (2000–2110)	0.00 (0.000)	50.8 (0.002)	Atmosphere brazing
BCuZn-A	910–954 (1670–1750)	50.8 (0.002)	127.0 (0.005)	Flux brazing
BMg-1	604–627 (1120–1160)	101.6 (0.004)	254.0 (0.010)	Flux brazing
BNi-1	1066–1204 (1950–2200)	50.8 (0.002)	127.0 (0.005)	General application

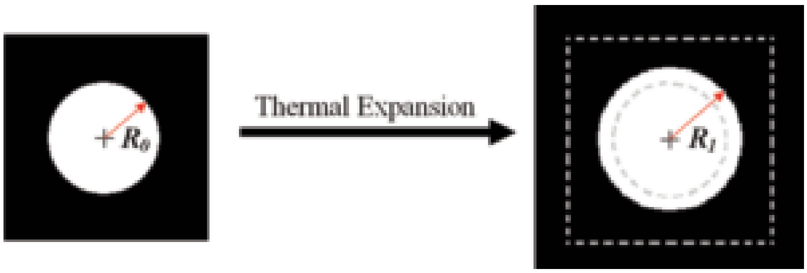

Fig. 3 — Schematic representation of thermal expansion of holed surfaces.

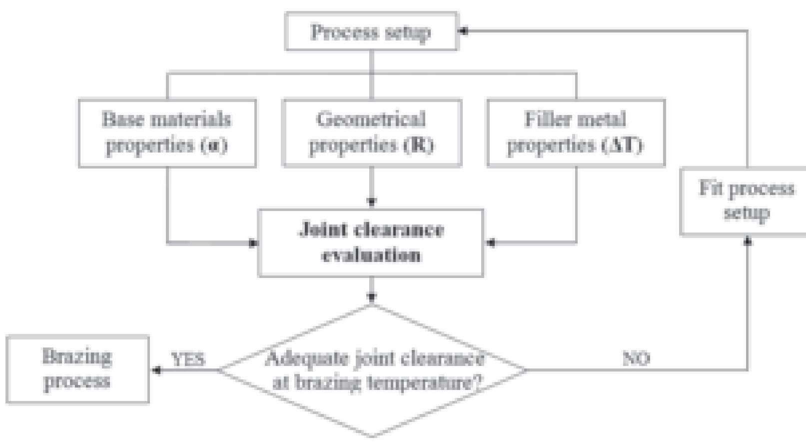

Fig. 4 — Procedure for evaluating and troubleshooting joint clearance incompatibility in brazing.

Table 2 — Required Parameters for Thermal Expansion Evaluation at Brazing Temperature

Geometrical Properties	Base material properties	Filler Metal Properties
Re_0 = 63.5 mm	α_e = 18.7 µm/m°C	ΔT = 1073°C
Ri_0 = 63.465 mm	αi = 13.9 µm/m°C	

clearance at the brazing temperature. Therefore, when designing a joint with dissimilar base materials, it is fundamental to consider the mismatch between the thermal expansion coefficients for calculating the actual joint clearance at the brazing temperature, which can be done by using Equation 5.

Evaluating and Troubleshooting a Real Application

A practical evaluation of the joint clearance at brazing temperature is presented by the proposed thermal expansion calculation for a dissimilar steel pipes ensemble, similar to the one presented schematically in Fig. 2.

The proposed example is an ensemble of an American Iron and Steel Institute (AISI) 304 stainless steel with 127-mm internal diameter (Re_0) external pipe and AISI 1020 carbon steel with 126.93-mm external diameter (Ri_0) internal pipe. Therefore, this joint has a 35 µm clearance at room temperature. The AISI 304 stainless steel and AISI 1020 steel present mean thermal expansion coefficients of 18.7 µm/m°C (α_e) and 13.9 µm/m°C (α_i), respectively (Ref. 5). A feasible filler metal for this ensemble is BCu-1, which requires a brazing temperature of at least 1093°C. Table 2 summarizes the initial brazing setup.

The application of Equation 2 for the given parameters results in a joint clearance of 357.0 µm at brazing temperature, which indicates an inadequate brazing setup for the BCu-1 filler metal, according to Table 1. Therefore, the joint design accordingly must be changed to provide the ideal conditions for complete penetration of the joint. Figure 4 illustrates the main project aspects that can be changed to minimize the thermal expansion coefficient mismatch effect.

Some of the possible modifications that can be implemented to reduce the

Table 3 — Adaptations to Reduce Thermal Expansion Coefficient Mismatch Effect on Brazing

Project Feature	Properties	Possible Modification
Base materials	α	Substitute base material to reduce α mismatch
Geometry	R	Modify base material dimensions and/or ensemble
Filler metal	ΔT	Substitute filler metal to reduce brazing temperature
Filler metal	Clearance tolerance	Use a filler metal indicated to widen joint clearances

effect of thermal expansion coefficient mismatch for brazing processes on dissimilar base material are listed in Table 3.

Thermal Expansion Coefficient Temperature Dependence

Linear thermal expansion coefficient α is a temperature-dependent property. However, a good approach can be obtained for most of the engineering materials using a constant value of α at room temperature for the joint clearance calculations. Any condition that demands higher accuracy or for brazing base materials with a thermal expansion coefficient that is highly dependent on temperature must be evaluated carefully. In these circumstances, a mean thermal expansion coefficient for most common engineering materials can be found in the literature (Ref. 5) for usual ranges of temperature. However, for specific materials or application, a better calculation can be attained by an integral analysis of α(T) function that can be obtained experimentally by using a dilatometer. For this case, Equation 3 may replace Equation 1.

6. Thermal expansion for coaxial profiles with temperature dependent α:

$$R_1^2 = R_0^2 \cdot (1 + 2 \cdot \int_{Ti}^{Tf} \alpha_n(T)dT) \qquad (6)$$

Conclusion

This article highlights a simple analytical model to evaluate joint clearances at brazing temperatures and a simple procedure for evaluating and troubleshooting joint clearance incompatibility on brazing processes for dissimilar materials. An example of the proposed methodology application to an ordinary pipe ensemble showed that the mismatch in thermal expansion coefficient can be a determining factor on success or failure of a brazing setup.♦

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