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Effects of Dissimilar Materials on Joint Properties

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The brazing of base materials with different physical properties, in particular, different thermal expansion coefficients can lead to the formation of thermally induced residual stress during cooling. The resulting residual stress may affect the mechanical strength of the final joint and its performance in service.

Such issues must be taken into consideration when designing the braze joint, choosing the brazing filler metal and brazing process parameters. It is necessary to keep the level of residual stress as low as possible in order to maintain the functionality of the brazed joint under service conditions.

Joining of dissimilar materials

The brazing cycle parameters effect the properties of the base materials to be joined; indeed in most cases only the stress-relieved physical properties of the base materials will be achievable in the final braze joint. Since some brazing operations are carried out above the austenization temperature for steels or optimum solution treatment temperature for age hardenable alloys it is difficult to optimize the mechanical properties and hence maximize the performance of the joint [1].

Differential thermal expansion

When brazing dissimilar materials the different thermal expansion behavior of the materials involved in the joint has to be taken into account. The thermal expansion of different materials is shown in **Figure 1.**

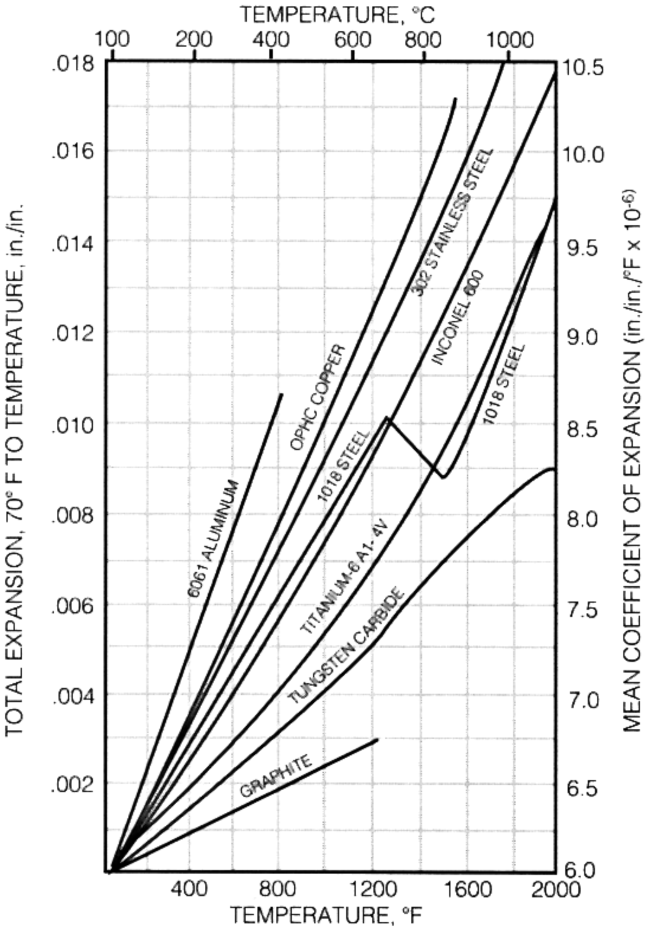

Fig. 1: Thermal expansion of different materials as function of temperature [1]

The variation in thermal expansion which occurs can affect the joint clearance at brazing temperature which is crucial for the success of the brazing operation. Sufficient clearance has to be maintained to ensure that capillary action takes place successfully during the brazing process. For example, consider a steel rod fitted into a tungsten carbide ring; the steel rod has a higher thermal expansion coefficient than the tungsten carbide ring leading to a reducing joint gap as the parts are heated to depending on the temperature and pressure being applied to it.

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the brazing temperature. Therefore, the clearance at room temperature is designed to be much greater to ensure an optimal gap size is reached at brazing temperature **(Figure 2)** [2].

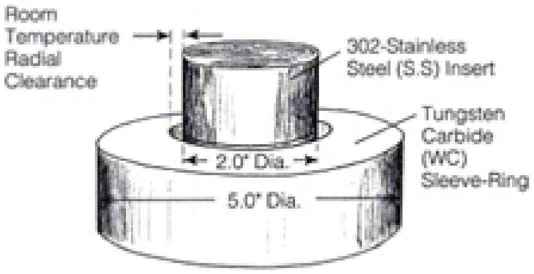

Fig. 2: Joint clearance at room temperature taking under consideration of different thermal expansion of parental materials

The main obstacle in maximizing bond strength and the mechanical properties of the joint when utilizing dissimilar materials is caused by the mismatch of the physical properties of the joint members.

When two materials with different thermal expansion coefficients are brazed the brazing filler metal must be strong enough to resist fracture and at least one of the base materials or the filler metal must yield during cooling.

Constrained thermal shrinkage during the cooling from brazing temperature after the filler metal has solidified can lead to the formation of thermally induced residual shear stress at the interface of the joint members. The stress distributions produced in the joint can be complex and in extreme cases can lead to distortion and cracking.

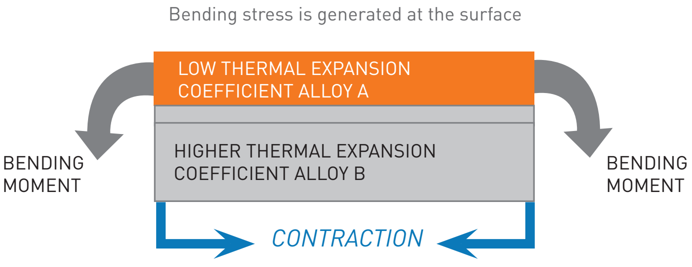

Fig. 3: The application of a contraction-induced bending moment in a carbide-to-steel brazed joint may well lead to cracking of the carbide

Residual tensile stress is the most problematic particularly when materials with low ductility are involved. In some instances, the base metals may not have the capability to yield and there is a tendency for brittle fracture on cooling. **Figure 3** shows how bending stress is induced in a Tungsten carbide to steel joint during cooling which may lead to cracking in the surface of the tungsten carbide.

Whenever possible the brazement should be designed to minimize the residual stresses within the joint. This is important because the applied stress plus the residual stress can make the joint prone to premature failure. Certainly, it is difficult to totally avoid residual stress and inevitably some will still remain in the joint [1].

Parameters / variables which impact residual stress

The magnitude of the thermally induced residual stress depends on the following influences/values:

- The difference of the thermal expansion coefficients of the joint members
- The construction / design and geometry of the component, in particular the component size
- The solidus temperature of the filler metal
- The ability of the filler metal to deform plastically without fracture
- The thickness of the brazing joint
- The mechanical properties of the joint members (elastic modulus / stiffness) [3]

Measures to reduce residual stress in a brazed joint

The opportunities available to reduce the residual stress after cooling are somewhat limited, as considered below:

Material selection is important as the thermal expansion coefficients of the materials involved cannot be altered. Therefore, where possible, select materials with comparable thermal expansion characteristics.

To reduce the internal stress level the component size should be kept as small as possible with respect to the functionality required.

A significant reduction of residual stress levels can often be achieved by using a filler metal with a lower solidus temperature, since the internal stress develops from the temperature when the filler metal solidifies.

Using a ductile filler metal that yields during the cooling cycle can prevent high stress between the two base metals. This, in particular, is necessary when the base materials do not possess sufficient ductility to yield; for example when tungsten carbide is brazed to steel.

A larger joint gap is also capable of decreasing the stress since it is easier to compensate the residual stress by yielding within a thicker layer of brazing filler metal. However, this depends on the type of braze filler metal deployed and the material being brazed; inappropriate selection can result in the formation of brittle centreline phases which can embrittle the joint [5].

A larger clearance is contrary to the recommendation to use tight clearances for achieving the best strength result of the braze joint. However, when using base metals with high differential thermal expansion such as carbide and steel the strength of the joint decreases with smaller clearances. The filler metal must absorb shrinkage stresses caused by the differential thermal expansion of the parts to be joined. If a clearance is too tight the stresses are concentrated leading to a reduction of joint strength.

Another alternative is to employ a soft ductile interlayer / spacer such as copper or nickel within the joint. In this context, one should avoid exposing the base metal with the low ductility (such as carbide) to tensile stress. An opportunity to achieve this is to use a geometry where the base metal steel substrate is at least three times thicker than the carbide component to which it is brazed.

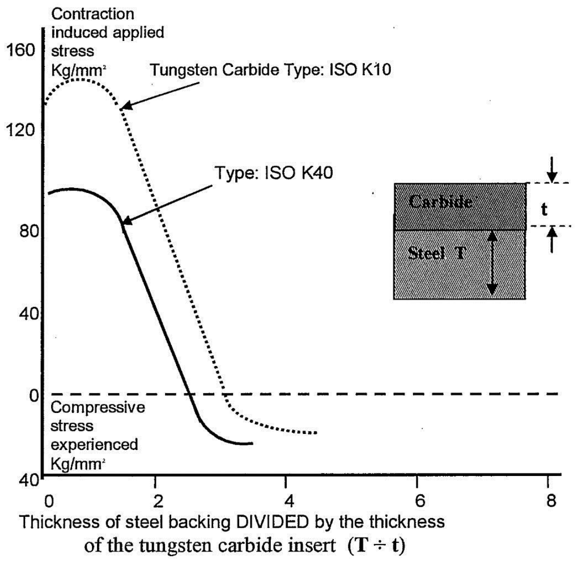

Fig. 4: Stress levels found in a brazed joint between tungsten carbide and steel that has cooled from a brazing tempera-ture of about 1000 ºC

Owing to the greater thickness of the steel substrate the brazed component has a higher stiffness which prevents it from bending / distorting, thus preventing tensile stress developing at the surface of the carbide.

Another mechanical property which affects the internal stress in the joint is the elastic modulus which represents a value for the stiffness of a material. A material with higher elastic modulus which is strained therefore exhibits higher stress levels compared to a material with lower elastic modulus and identical elongation. Since the elastic modulus of the material cannot be altered the only alternative is to select another material with a lower elastic modulus.

All these parameters which affect the properties and lifetime of the joint or tool are interrelated and the complexity results from the interdependency of these different parameters.

The situation is further complicated if the materials undergo transformation with an associated volume change on heating and cooling. For example, many steels have a unique property called polymorphism, which, in principle, means that the metal can exist in alternate crystal forms (crystal lattices structures), This transformation implies a volume change. While changing from a BCC to an FCC crystal structure during heating, two things occur that cause shrinkage of the metal lattice structure:[1] heat is absorbed during the phase change and[2] the packing of atoms becomes more efficient in FCC, allowing more iron atoms to fit in a given space than in the BCC alignment. However, once the phase change has been completed, further heating will cause the steel to once again expand. The opposite reactions occur when the steel is cooled. Differential heating rates within the parts and the rate at which parts are heated and cooled also influence the degree of distortion observed.

These seemingly insignificant "reversals" in thermal expansion and contraction curves for alloys such as 1018 steel can lead to major distortion problems if these changes are not taken into account [4].

References

[1] American Welding Society (AWS), Brazing handbook, 4th edition, 1991

[2] Brazing fundamentals, Differential metal expansion, Vol.2, No 2, 1993, Wall Colmonoy website

[3] "Hartloeten und Hochtemperaturloeten – Grundlagen und Anwendung" L. Dorn, K. Iversen, M. Stroiczek, W. Tillmann, W. Weise, Kontakt & Studium Band 677, Expert Verlag Renningen, 2007

[4] Brazing Fundamentals, Differential Metal Expansion - Part 2, Wall Colmonoy website

[5] Advances in Technology of Materials and Materials Processing, Chaturvedi, M.

About Wall Colmonoy and Brazing

Wall Colmonoy joins parts for high-temperature and corrosion applications using **Nicrobraz®**, **Niferobraz®**, and **CuBraz™** brazing filler metals and brazing aids.

The pioneer of high-temperature brazing, Wall Colmonoy's expert brazing engineer, Bob Peaslee, invented a new brazing technology involving nickel-based filler metals and hydrogen atmosphere furnaces in 1950. As a result, the new filler metal, Nicrobraz®, was created.

Today, Nicrobraz®, Niferobraz®, and CuBraz™ brazing filler metals are used in a variety of industries including aerospace, oil & gas, steel, energy, food, automotive, rail and defense, meeting AWS, AMS, G.E., Honeywell, Pratt & Whitney and Rolls-Royce specifications. Nicrobraz products are available as powder, paste, transfer tape, rods and sheets in a full range of sizes and specifications. Wall Colmonoy also custom formulates brazing filler metals to meet customer specific requirements.

Aerobraze Engineered Technologies, a division of Wall Colmonoy, manufactures engineered components and provides technological solutions for the aerospace, energy, defense and transportation industries. This division meets aerospace quality standards in applications using the process of brazing, surfacing, welding, thermal processing, fabricating, machining and overhauling. Aerobraze Engineered Technologies has the engineering expertise to take concepts from design to prototype to production.