Brazing cast iron-no longer a problem?

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An alloy to solve cast iron brazing problems

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Where factors combine to make a single casting impractical or unsuitable, methods of joining cast iron may be considered. The various forms of cast iron are considered with regard to their susceptibility to structural changes during brazing. Established brazing procedures are outlined and recent work on grey irons is discussed in detail.

Fabrication of assemblies involving the brazing of cast iron, either to itself or other wrought metals, tends to be viewed with some apprehension. This may well be due to past experience which showed joint quality to be unusually inconsistent, if not generally poor. Doubts may also exist about the ability of cast iron to withstand brazing without serious losses in its mechanical properties.

In consequence designs involving the brazing of cast iron may often be discarded in favour of more intricate and costly castings or even a different parent metal. However, attention to the heating cycle and the use of a suitable filler metal permit consistently sound and strong joints to be achieved without damaging the cast iron.

Cast iron

Cast iron, like low alloy steel, is a general term used to classify a wide variety of iron alloys with similar carbon contents. The microstructure and mechanical properties of cast irons varies considerably depending on the form in which this carbon is present. The ease with which a cast iron may be brazed is also related to its microstructure, making it essential to ascertain the exact nature of the material to be joined before brazing.

All cast irons contain 2.4—4.0% carbon. The addition of selected alloying elements and variations in heat treatment alter the structure. There are four main types of cast iron, grouping being based on the form taken by the carbon present in the casting:

White iron

Generally made simply by limiting the silicon content to less than 1.3%. Accelerated cooling or the addition of chromium promotes the formation of cementite. The name refers to the bright fracture produced by the presence of the brittle cementite.

Grey iron

The best known form of cast iron, it contains 2—5% silicon to induce the formation of discrete particles of graphite rather than cementite (Fe_3C). The graphite takes the form of flakes which are inherently weak. Consequently fracture of the material invariably occurs through them, giving rise to a dull grey appearance.

Malleable iron

Cementite, as formed in white irons, is only metastable and when subject to prolonged heat treatment at temperatures around 900°C will decompose to form austentite and discrete rosette-shaped graphite particles. In this form the graphite has a far less deleterious effect on the strength and ductility of the casting than the flakes in grey iron.

Spheroidal — graphite irons

Irons containing free graphite in the form of rough spheres, rather than flakes, can be produced directly on casting by the addition of elements such as magnesium and cerium. These irons generally offer greater strength and ductility than grey iron while retaining excellent casting and machining properties. The matrix may be controlled to consist entirely of ferrite, pearlite or a combination of these two to vary the strength and hardness.

Brazing considerations

Brazing cast iron involves two main considerations:

- Susceptibility of the iron to structural changes when heated above its transformation temperature
- Whether or not the iron contains free graphite and if so in what form

Two other aspects of brazing cast irons should not be overlooked.

First, cast components have a sand impregnated, heavily oxidised skin; brazing directly onto this skin should not be attempted. Wetting is generally poor and even where a bond is achieved the skin is likely to be torn from the body of the casting.

Second, most cast irons have relatively low thermal

conductivity combined with a moderate coefficient of expansion and low ductility. In view of this combination of properties heating and cooling cycles should be chosen to avoid excessive stresses due to steep thermal gradients.

Structural changes due to brazing

The matrix of a grey iron, pearlitic S.G. or pearlitic malleable iron will change to austenite if the material is heated to above its transformation temperature. The exact transformation temperature varies depending upon the analysis of the iron, but is about 700^0C. The form taken by the austenite on cooling will depend on the rate at which this cooling takes place. Extremely fast cooling from temperatures in excess of 700^0C could result in the formation of martensite, although this would be most unlikely to occur in brazing. It is quite possible however, that cooling rates significantly faster than those seen during casting could be achieved, with the danger that an unacceptably fine pearlite structure could be produced. Alternatively, prolonged cooling as might result from furnace brazing, could result in a significantly softer structure due to increased ferrite in the matrix.

The use of a brazing alloy with a flow point below the transformation temperature ensures that the structure of the iron is not altered. Where the use of a filler metal with a brazing temperature in excess of the transformation temperature is envisaged, it is advisable to conduct brazing trials involving checks on the structure of the cast iron. On the basis of these trials it should then be possible to adopt a closely controlled brazing procedure which will ensure a consistently satisfactory brazed joint and cast iron structure.

The production procedure employed to produce ferritic S.G. iron requires that cooling be arrested at approximately the transformation temperature for a period of several hours. Normal air cooling through this temperature will result in the formation of a largely pearlitic structure. Consequently if a ferritic S.G. iron is brazed above the transformation temperature a serious loss in ductility and impact resistance will result. Blackheart malleable iron is similarly affected and the use of low temperature silver brazing alloys is recommended.

The cementite present in white iron does not begin to break down until it reaches approximately 900^0C. Consequently brazing alloys with liquidus temperatures up to 850^0C can be used with confidence.

Free graphite's effect on wetting

The presence and form of free graphite in a cast iron will determine the ease with which a brazing alloy can be expected to wet on its surface. Graphite is of course a non-metallic element and cannot be brazed by conventional silver or brass brazing alloys. Its presence on the surface of a cast iron can therefore be expected to have a deleterious effect on wetting. It should be remembered that a carbon content of 3.0% by weight represents somewhere in the region of 10% by volume. This situation may be aggravated by machining and general handling which can spread a light film of graphite over the surface.

White iron is rarely brazed, but since it contains no free graphite good wetting could be expected with any of the conventional silver brazing alloys such as BS1845 AG1. Similarly, Whiteheart malleable iron, which has a decarbonized surface similar to low carbon steel, is readily wetted. Of the cast irons containing free graphite the S.G. grades present the least difficulty in wetting. This is because the graphite present offers the minimum surface area with little danger of gross surface contamination. Flake graphites are undoubtedly the worst with regard to wetting, with the high carbon alloys being proportionally more troublesome than those containing 2% by weight of carbon.

To ensure good brazed joint quality on grey irons special surface preparation techniques have been recommended.

These techniques may also be used on malleable and S.G. irons although it is not generally found to be necessary. Perhaps the simplest method of removing free graphite is to burn it from the surface using an oxidising oxy-acetylene flame. This approach can prove useful for one-off jobs where a skilled brazer is employed, but is not attractive at high production rates.

An alternative is shot blasting which tends to preferentially remove the brittle graphite flakes from the surface. The success of this approach will clearly be governed by access to the brazed joint surfaces. Where large numbers of components are to be cleaned the most effective and practical methods of degraphitising are based on the use of molten salt baths. A simple treatment would require fifteen minutes immersion in a 50/50 mixture of sodium and potassium nitrates at about 400^0C.

A more sophisticated cleaning method involves electrochemical treatment in a molten salt bath to remove both graphite and casting skin.

Once grey iron has been degreased and degraphitised it can be readily brazed using any of the filler metals commonly associated with brazing mild steel. The general purpose brazing fluxes associated with the filler metal in use are quite adequate. Low temperature silver brazing alloys are generally preferred because of the possible structural changes previously outlined. Nickel bearing alloys such as BS1845 AG9 are particularly favoured since they appear to give greater joint strength.

Alternative to degraphitisation

The efficiency of the various cleaning methods mentioned above varies considerably. One factor in common is that they all add considerably to production costs and time. Consequently, it is not uncommon for grey iron brazing to be attempted without a specialised cleaning procedure. Satisfactory joints can sometimes be obtained. Bearing in mind the wide variations in material specifications and the relatively undemanding requirements associated with some brazed joints, this is not incompatible with the concept of poor wetting.

Production experience has indicated that nickel-bearing silver brazing alloys such as AG9 (a 50% Ag-Cu-Zn-Cd-Ni alloy) offer improved wetting on as-machined grey iron compared with simple quaternary or ternary alloys such as AG1. However, while both alloys improve wetting difficulty may still be encountered, AG9 is reknowned for its extremely sluggish flow characteristics which require above-average brazing skills if good capillary penetration is to be achieved.

In response to a request from industry, Johnson Matthey Metals undertook some work to find a low temperature silver brazing alloy capable of wetting untreated grey iron. To ensure its suitability for all applications the alloy also had to be cadmium-free. Working within these constraints the most promising alloys appeared to be those in the Ag-Cu-Zn-Mn-Ni system. Manganese is known to improve wetting on tungsten carbides and it also appears to increase considerably the fluidity of nickel-bearing silver brazing alloys such as AG9. Nickel additions had of course already shown themselves beneficial although the reason for this has yet to be established.

Wetting trials

Simple spreading tests were conducted on a standard grey iron using the commercially available alloys listed in Table 1. In each case the alloy readily wet and spread over the surface of the grey iron.

Penetration tests on lap joints were used to simulate brazing. Brazing was carried out in a muffle furnace without a protective atmosphere, the joint was pre-fluxed with standard Easy-flo flux and the brazing alloy was placed at one end of the joints as a pellet. In all cases the brazing alloy readily wetted the grey iron and ran through the joint producing a uniform fillet at either end.

Mechanical properties of brazed joints

Argo-braze 49H was selected for tensile and shear strength trials as it offers a relatively low brazing temperature combined with a relatively high nickel and manganese content. Tensile and shear strength specimens were produced and brazed in accordance with DIN 8525: March 1965. The grey irons selected for this work were the low phosphorus and high phosphorus grades specified in Table 2. Other than degreasing no pre-braze cleaning operation was used. All brazed joints were made using Easy-flo flux and allowed to air cool after brazing.

The brazed joints appeared visually sound and metallographic examination showed that wetting had been very good. Fig. 1 shows a butt joint in low P grey iron. Where graphite flakes break the surface there has been no significant effect on the flow

Table 1. Manganese bearing alloys used for trials on grey iron

Alloy	Composition					Melting range
Argo-braze 49H (BS1845 AG18)	Ag 49%	Cu 16%	Zn 23%	Ni 4.5%	Mn 7.5%	625—705°C
Argo-braze 25	Ag 25%	Cu 38%	Zn 33%	Ni 2.0%	Mn 2.0%	710—810°C

Nominal composition of grey iron:
3.25% C, 2.35% Si, 0.6% Mn, 0.35% P max, 0.155% S max.

Argo-braze 25 is covered by British Patent No. 1462661.

Table 2. Analysis of grey irons used for tensile and shear strength tests

	Total C	Si	Mn	S	P
Low P grey iron	2.82	1.61	0.54	0.152	0.11
High P grey iron	3.07	2.65	0.51	0.035	1.01

Table 3. Mechanical tests on low P cast iron joints

Specimen type	Tensile Strength N/mm²	Shear stress at failure N/mm²	Position of failure
Tensile	289	—	braze/cast iron
Tensile	304	—	cast iron
Tensile	272	—	braze/cast iron
Tensile	293	—	braze/cast iron
Tensile	281	—	cast iron
Shear	171	105	cast iron
Shear	212	130	cast iron
Shear	172	105	cast iron
Shear	197	120	cast iron
Shear	175	106	cast iron

*Note:* shear stress is that when the cast iron broke.

Table 4. Mechanical tests on high P cast iron joints

| Specimen type	Tensile Strength N/mm²	Shear stress at failure N/mm²	Position of failure
Tensile	205	—	braze/cast iron
Tensile	201	—	braze/cast iron
Tensile	221	—	cast iron
Tensile	210	—	braze/cast iron
Tensile	207	—	braze/cast iron
Shear	104	63	cast iron
Shear	105	64	cast iron
Shear	112	69	cast iron
Shear	121	73	cast iron
Shear	118	71	cast iron

Note: shear stress is that when the cast iron broke.

of the alloy. Similar results were obtained on high P grey iron and Fig. 2 shows excellent penetration into crevices which are believed to have been formed by the fracture of graphite flakes.

The results of the mechanical tests are given in Tables 3 and 4. The behaviour of the low and high phosphorus alloys was very similar. Tensile specimens frequently failed well away from the joint and where the fracture path went through the brazed joint it was still largely in the cast iron. The tensile strengths recorded are approximately those expected for the base metal indicating
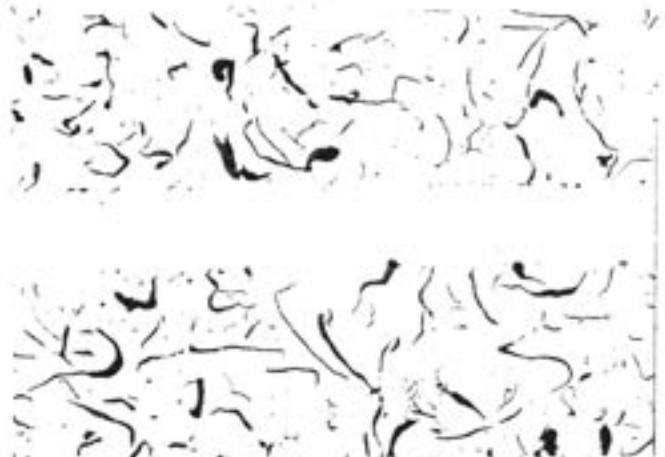
Fig. 1 Argo-braze 49H on low phosphorous grey iron.
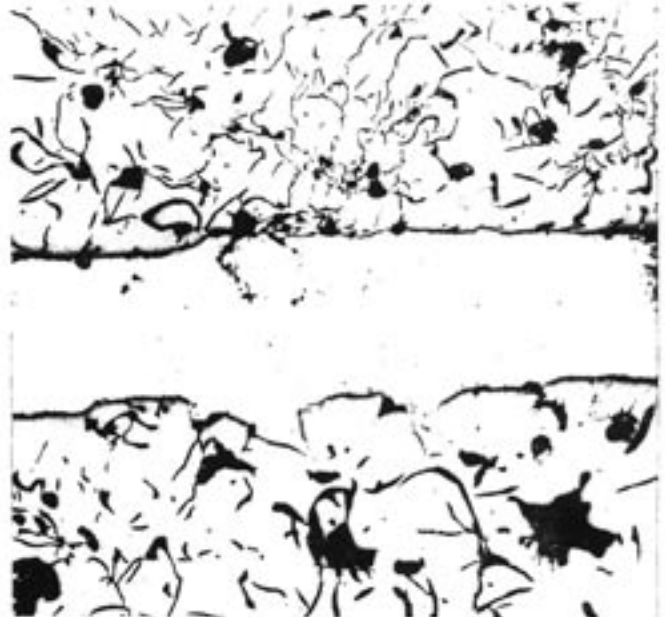
Fig. 2 Argo-braze 49H fills a surface crack on high phosphorous grey iron.
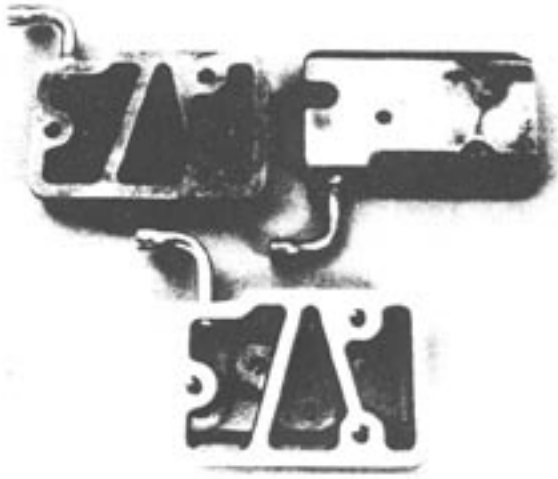
Fig. 3 Grey iron compressor discharge muffler cover brazed to steel tubing. Joint is fully penetrated.

Discussion

The results of the wetting and mechanical strength trials with Argo-braze 49H have shown that strong joints can be consistently achieved on grey iron without degraphitisation. The brazing temperature required for this alloy is only slightly above 700^{0}C, thereby virtually eliminating problems due to structural changes, provided the cast iron is not overheated and the time at brazing temperature is kept to a minimum. Where test samples have indicated that a high brazing temperature can be accommodated, lower silver content alloys such as Argo-braze 25 may be used as an alternative on grey iron. Such alloys are not suitable for ferritic S.G. iron.

A grey iron compressor discharge muffler and steel tube elbow, brazed together using a preplaced ring of Argo-braze 49H, and fixed gas/air burners, is shown in Fig. 3. This assembly is typical of applications where brazing is used to join cast iron to steel, either to produce an assembly combining the physical properties of these materials or simply to reduce casting complexity and cost.

Other examples include the brazing of a gear with cast teeth and splined hub and a cast throttle control lever to a steel shaft. The availability of manganese bearing alloys, such as Argo-braze 49H, which will readily wet untreated grey iron should serve to increase the use of brazing in these areas.

Conclusion

- Alloys in the Ag-Cu-Zn-Ni-Mn system readily wet the untreated grey irons examined.
- Using Argo-braze 49H excellent brazed joints can be produced in standard grey irons without a significant loss in their mechanical properties, or the need for closely controlled cooling rates.