Brazing Cemented Carbides: Specifics, Braze Optimization and Custom-Designed METGLAS^{R*} Brazing Filler Metals

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When cemented carbide lap joints are loaded in shear, or in a complex shear/bending mode, one notices that fracture initiates and occurs predominantly in the fillet area. The critical stress for the braze fracture under both types of loading is substantially lower than that of a virgin cemented carbide: thus, brazing undercuts the strength potential of cemented carbide joints. In order to improve this deficiency, we studied the effects of r. f. induction heating, filler metal composition, fillet formation, and various mechanical surface treatments of the brazed parts. As a result, a new model is presented explaining the mechanism of liquid filler metal/cemented carbide interaction and showing the ways to improve substantially the strength of joints.

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Cemented carbide brazements, particularly those which are integral parts of oil well drill bits contribute enormously to the world economy. Indeed, the majority of oil well drilling crowns are furnished with cemented carbide or cemented carbide/polycrystalline diamond tips which are joined to the cemented carbide studs by brazing. Because such brazements are utilized at high service temperature, about 400C and under high erosive/corrosive conditions, they should exhibit high temperature strength and resistance to corrosion.

In general, brazement performance is determined by a number of interrelated factors which are associated with the nature of both filler and base metals. These factors include (a) the state of the base metal after heating to the brazing temperature and reaction with liquid filler metal, particularly in the fillet area, (b) microstructure of the braze and fillets, and (c) the geometrical form of the latter. Cemented carbide is a rather brittle material, similar to ceramics. Particular attention, therefore, should be paid to how brazing affects surface area of brazed parts where cracks initiate.

In spite of the importance of cemented carbide brazing, only a few works dealing with this topic were published recently (1,2). This paper describes results of optimization of cemented carbide brazing, which includes surface treatment of parts *before and after* heating and the application of a new advantageous nickel-palladium-base brazing filler metal. We also show the importance of forming a lean, small fillet upon brazing in order to avoid excessive erosion under fillets, leading to crack nucleation and growth.

EXPERIMENTAL

In order to separate effects of r.f. heating, surface mechanical treatment, nature of a filler metal, and brazing procedure on brazement performance we measured the following properties: (1) flexural strength of cemented carbide plates as a function of heating procedure and various sample surface treatments, (2) shear strength of lap-type brazements produced using various filler metals, and (3) flexural strength of the samples subjected to different surface treatments and brazed with only one filler metal having the best shear strength.

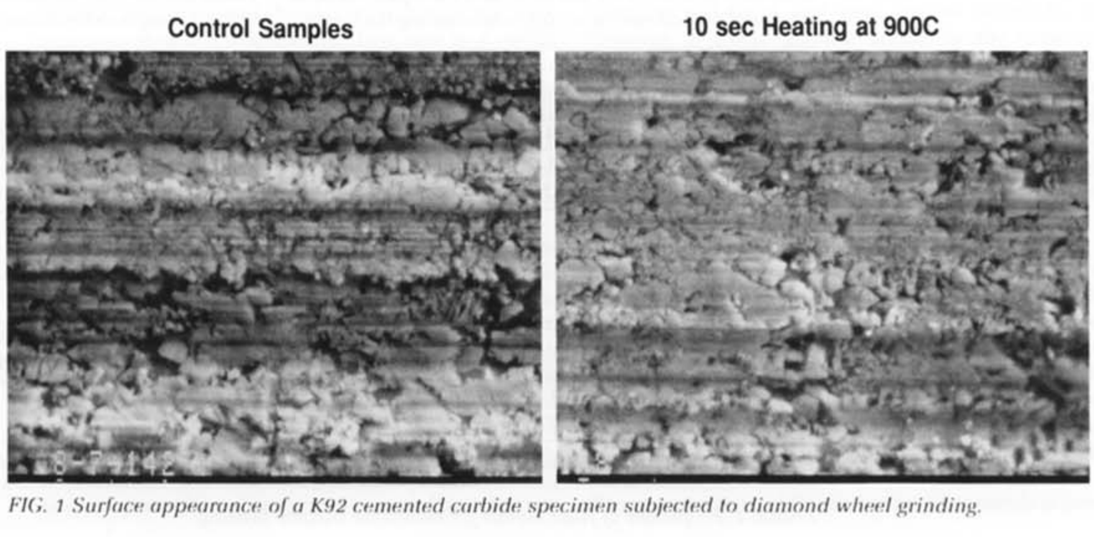


FIG. 1 Surface appearance of a K92 cemented carbide specimen subjected to diamond wheel grinding.

* METGLAS is a registered trademark of Allied-Signal Inc. for rapidly solidified alloys

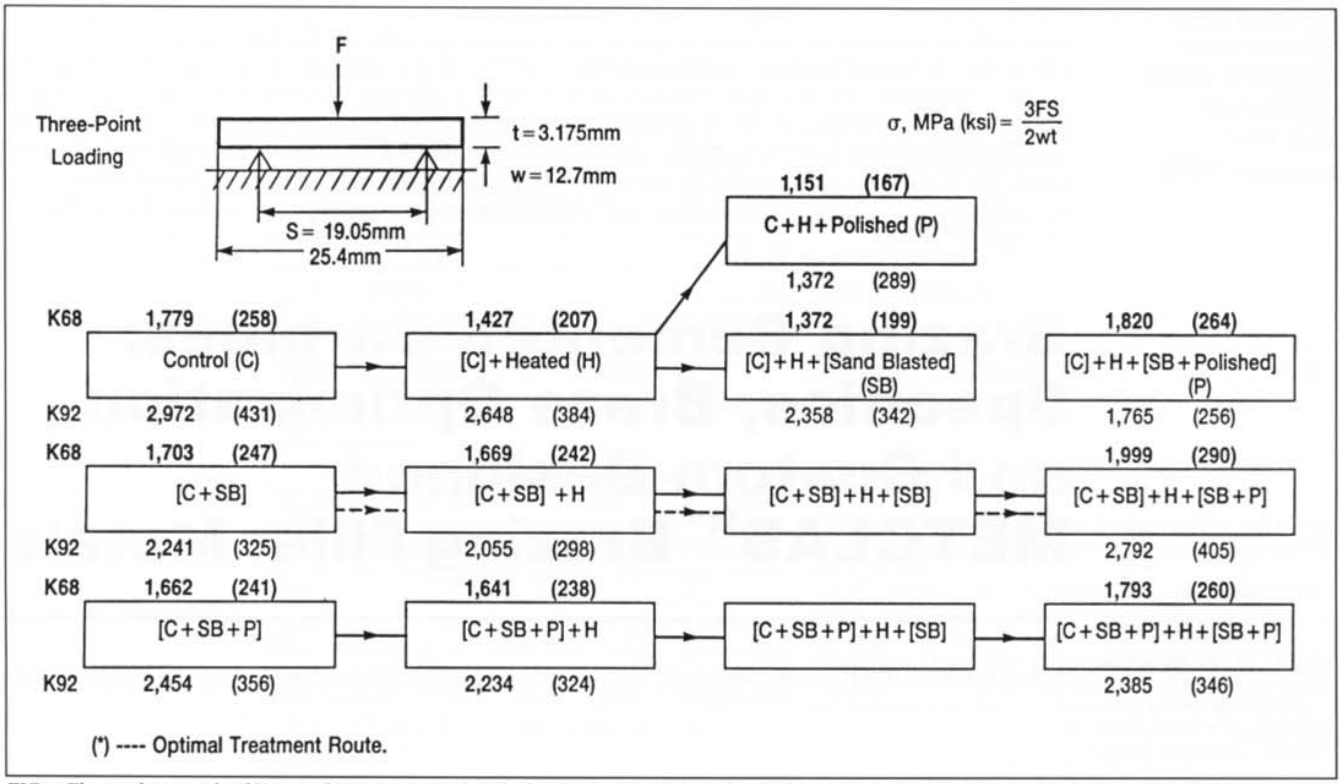


FIG. 2 Flexural strength of K68 and K92 cemented carbide plates, MPa (ksi) subjected to various surface treatments before and after heating. The heating procedure is analogous to that applied often during brazing of various tools.

All samples for mechanical testing were produced by Kennametal using two grades K68 and K92, of cemented carbide containing 6 and 15 wt.% Co, correspondingly. Samples were cut into rectangular shapes and ground using a 200 grit diamond wheel. Fig. 1 shows the appearance of the polished sample surface under high magnification, revealing a network of grooves which outline cemented carbide grains.

It is well known that grit blasting or shot peening of cemented carbide improves flow of molten filler metal (1). At the same time, shot peening is a treatment which creates compressive stresses in the surface of many materials, thus preventing development of fatigue crack initiation and propagation (3).

In the present work, the surface treatment consisted of the sand-blasting by 100 grit for 2 min/side at 0.5 MPa air pressure and, in some cases, polishing. The latter was performed for 1 min/side with 5 μm Al_2O_3 slurry. Polishing was used to both clean the surface of possible debris and to make it smoother. Heating of both single plates and of brazed sets was made using a 330 kHz induction generator. In the first case, each plate sample was heated 20-25 sec. at 1010C, while during the brazing operation, samples were heated to a temperature about 50C above the melting point of each particular filler metal tested. This procedure simulates what is used in the industrial brazing of cutting and drilling tools. Joint shear strength and 3-point bend tests were performed on a standard Instron machine with an extension rate 1.27mm/min (0.05 ins/min) using a specially designed sliding guide (4) and a standard Instron bench. Each mechanical strength value given is the mean result of five samples treated identically. Metallographic observations of element distribution within the brazements were carried using a JEOL-840 scanning electron microscope (SEM) equipped with a two wavelength spectrometer and an energy dispersive TRACOR spectrometer (EDAX).

RESULTS AND DISCUSSION

Effect of Heating in R. F. Field and of Surface Treatment on Strength of Cemented Carbide

These effects were observed on the following samples: control samples after diamond grinding, designated (C);

Alloy Designation	Nominal Chemical Composition, wt(at) % Cu	Co	Mn	Ni	Mo	Si	B	Pd	Au	Fe	Cr	Shear Strength, MPa (ksi)	Melt Range, °C(°F) Sol.	Liq.
Cocuman,	58.5	10	31.5	-	-	-	-	-	-	-	-	216	910	1000
WESCO	(53.5)	(10.2)	(43.5)									(31.4)	(1670)	(1832)
Gold-Nickel	-	-	-	18.0	-	-	-	-	82.0	-	-	174	925	985
82-18				(42.4)					(57.6)			(25.2)	(1695)	(1805)
Johnson &														
Matthew														
METGLAS* Alloy	-	-	-	55.52	-	-	2.7	32.25	-	.93	8.6	121	900	1010
MBF-1002	-	-	-	(56.14)	-	-	(14.93)	(18.09)		(.95)	(9.87)	(17.5)	(1652)	(1850)
METGLAS* Alloy	-	5.0	-	40.0	4.5	5.0	-	45.5	-	-	-	257	847	895
MBF-1011	-	(5.37)	-	(48.02)	(3.3)	(12.55)		(30.14)	-	-	-	(37.3)	(1556)	(1643)

* Cemented carbide K68 grade containing 6 wt.% Co is used as both base metals being brazed.

TABLE 1. Properties of filler metals for cemented carbide brazing.

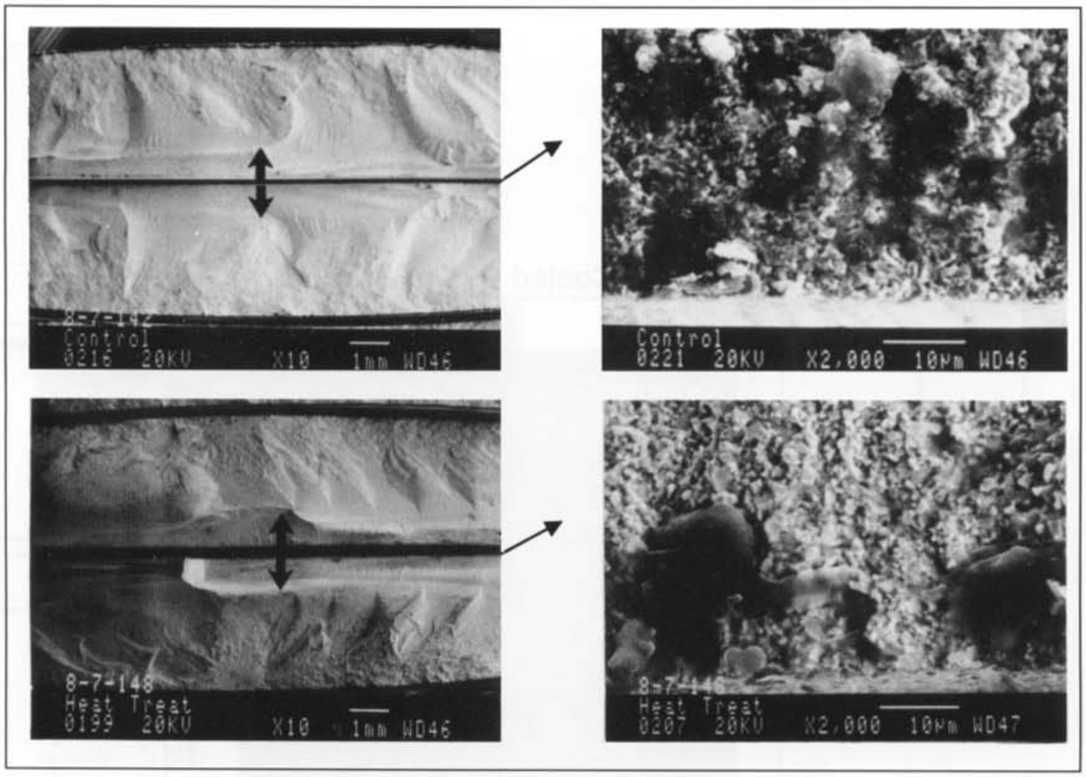


FIG. 3 SEM micrographs of two matching fracture faces of a K92 plate subjected to 3-point loading before and after heating. Solid arrows show the direction of loading. The surface area of the heated sample contains large regions with glassy fracture appearance which is characteristic of the transgranular brittle fracture mode.

sand blasted samples (C+SB) and samples subjected to polishing after sand blasting (C+SB+P). All three groups were heated (H) and afterwards *again* subjected to SB and SB+P. Strength measurements were carried out after each consecutive step. The results are given in Fig. 2 in a flow chart mode. Fig. 2 also shows the sample dimensions and a schematic diagram of the loading used. As follows from these data, sand blasting and subsequent polishing *before heating* decrease the strength of both K68 and K92 grade samples. Subsequent heating decreases strength even more. However, if sand-blasting *and* polishing are applied *after heating*, a recovery or even an increase of the plate strength (as in the case of K68 grade) is observed. In order to explain these results, one should remember that a short term r.f. heating is an inherently nonuniform process: namely, the thin surface layer is overheated relative to the sample core, whereas each local microstructural constituent is exposed to a different temperature. This happens because the depth of field penetration into the cemented carbide sample is thin and because its constituents, Co and WC, have different electrical resistivity and thermal conductivity (5). As a consequence of this overheating, there may be a partial depletion of cobalt at the surface layer because cobalt melts and evaporates at a substantially lower temperature than WC. This leads to formation of grooves surrounding cemented carbide crystals, thus causing a partial loss of bonding between constituent phases. These grooves assist crack initiation and propagation, resulting in a brittle mode of fraction.

A fast heating/cooling cycle results in deleterious thermal stresses which are particularly strong at sample surfaces, edges and corners. Fig. 3 demonstrates the different fracture faces of control and heated samples and compressive stresses. Indeed, all fracture faces have an integranular fracture mode in the control sample (Fig.3a), whereas large surface areas have encountered brittle glassy fracture in a heated sample (Fig. 3b). As a result, a substantial drop in strength after heating is observed. Sandblasting and polishing after heating removes part of the deteriorated material and thereby decreases thermal stresses, which results in the observed recovery of strength.

The same sandblasting and polishing operations made before heating obviously deteriorates the material which, in turn, leads to a loss of strength. However, the microstructural changes introduced by such treatments are not easy to identify.

Effect of the Brazing Filler Metal Composition

The existing filler metals for usage at elevated temperature, such as Au-18Ni and copper-based Cu-10Co-31.5Mn alloys braze well but suffer from a rather high melting temperature which promotes the possibility of high thermal stresses that could detrimentally affect diamond. Also, a low rupture strength at elevated temperature may result. In addition, the copper-base alloy has low corrosion resistance because of its high manganese content. More recently, it was shown that nickel-palladium base METGLAS alloy MBF-1002 exhibits high temperature strength, good corrosion resistance and good erosive resistance (6). However, a brittle fracture occurs in the cemented carbide parts in the vicinity of the joint at room temperature. Furthermore, metallographic analysis of joints brazed with METGLAS alloy MBF-1002 clearly indicates the formation of a detrimental microporosity at the interfaces of both cemented carbide parts (Fig. 4). similar microporosity is also observed in joints brazed with Au-18Ni alloy.

SEM EDAX elemental analysis data shown in Fig. 4 clearly demonstrates that this porosity is formed due to leaching of cobalt out of cemented carbide: the higher the brazing temperature, the more intensive the leaching. This process is, in fact, a result of unbalanced cobalt diffusion from the base metal into a layer of liquid filler alloy which contains no cobalt, such as MBF-1002 and Au-18Ni. In order to decrease cobalt concentration gradient, a new METGLAS alloy, MBF-1011, containing cobalt and molybdenum was developed.

The concentration of this and other filler metals is given

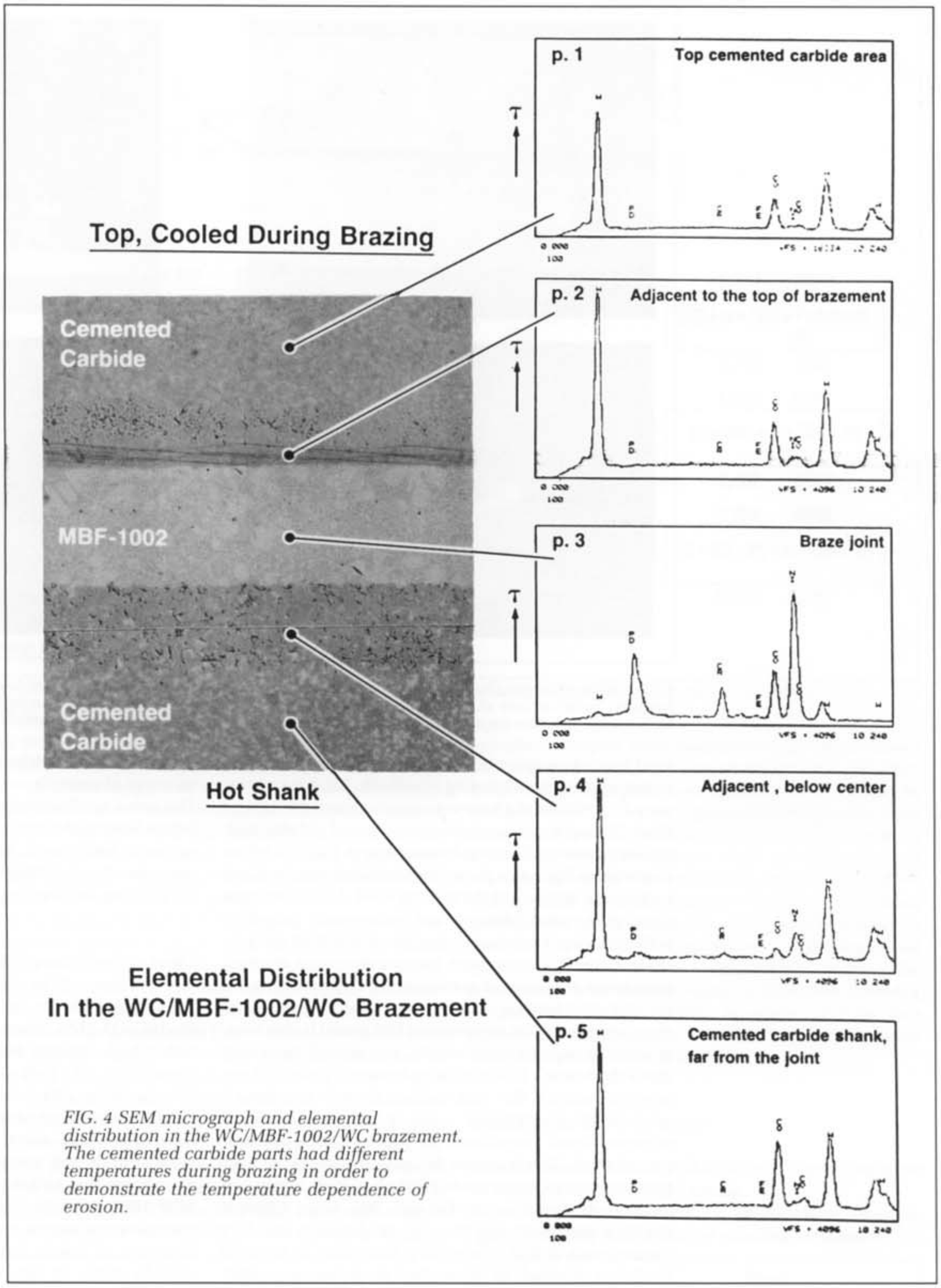
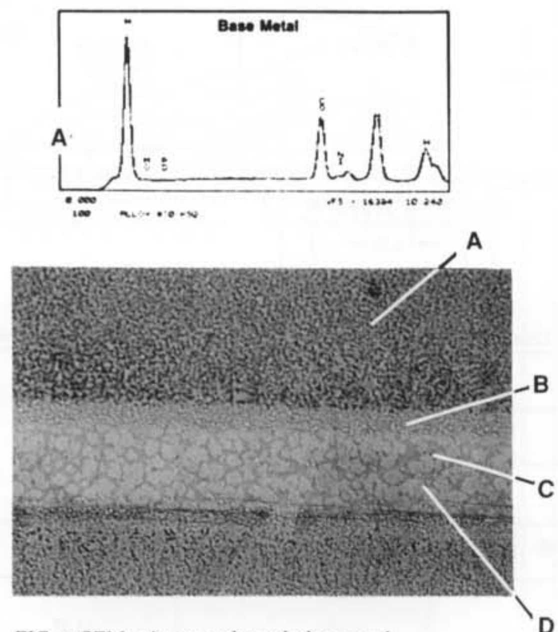


FIG. 4 SEM micrograph and elemental distribution in the WC/MBF-1002/WC brazement. The cemented carbide parts had different temperatures during brazing in order to demonstrate the temperature dependence of erosion.

in Table 1. Cobalt is added to decrease the cobalt concentration gradient across the cemented carbide/joint interface, thus diminishing substantially the driving force for unidirectional diffusion of cobalt out of cemented carbide base material. The role of molybdenum in the MBF-1011 alloy is to preserve the low melting temperature of the alloy while decreasing the overall mass transfer (mobility) of its atomic species. Moreover, while this alloy has only minimal silicon concentration and no boron, its chemistry is still sufficient to form a ductile, amorphous foil upon rapid solidification. The minimum concentration of metalloid elements also decreases wetting and fillet formation, because the lower silicon concentration results in higher liquid metal surface tension and lower tendency for the filler metal to spread. The latter, as will be shown later in this paper, has an important detrimental effect on brazement performance.

Fig. 5 demonstrates the absence of porosity in the interface area and rather moderate leaching of cobalt. Moreover, the eutectic microstructure of the braze formed upon its solidification has a favourable morphology: rounded particles of the intermetallic $(Ni, Pd, Co, Mo)_3 Si$ phase are evenly distributed in the ductile β- (Ni, Pd, Co, Mo) solid/solution matrix. As a result, the shear strength of the samples produced using METGLAS MBF-1011 is highest among competing alloys (Table 1). This new MBF-1011 composition melts completely below 900C. Therefore, its application not only reduces the thermal stresses in brazements but also preserves cemented carbide/polycrystalline tips from detrimental diamond graphitization.



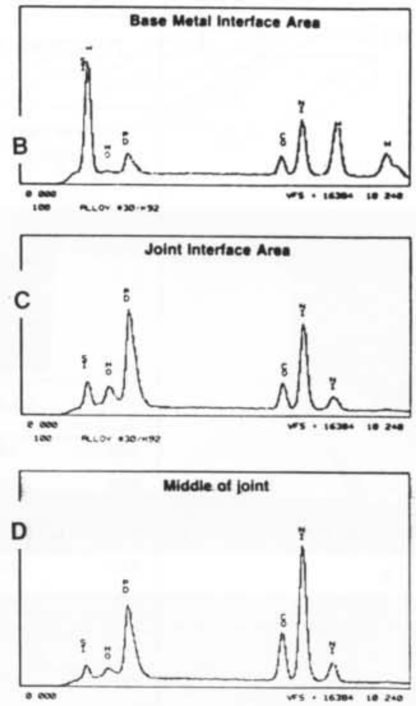


FIG. 5 SEM micrograph and elemental distribution in the WC/MBF-1011/WC brazement. Palladium and nickel diffuse into the base metal but molybdenum does not. Cobalt leaching is moderate. Base metal interface does not show porosity. (x 300)

Effect of Fillet Formation and Surface Treatment on Brazement Performance

When cemented carbide lap joints are loaded in shear (Fig. 6) or in a complex shear/bending mode, as in the case of studs massively supported by the cemented carbide base, fracture initiates and occurs predominantely in the fillet area. Moreover, the critical stress for base material fracture may be substantially lower than that of the base in the virgin, unbrazed state.

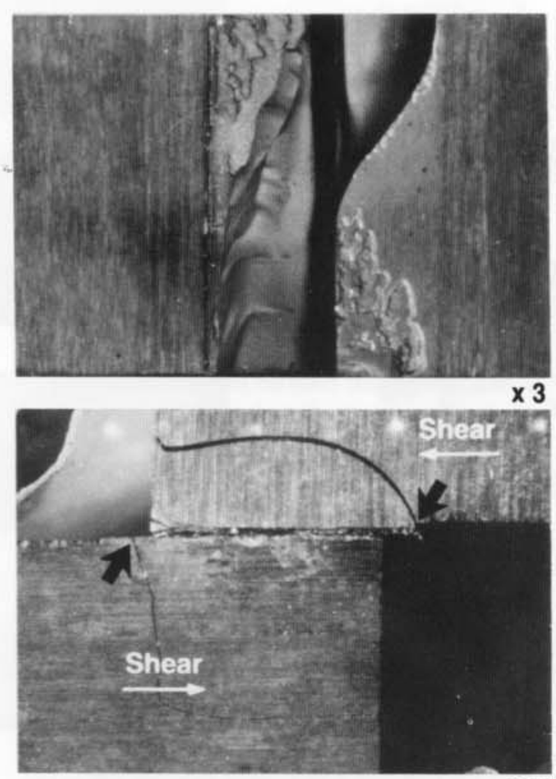


FIG. 6 Fracture of brazed K68 cemented carbide plates under shear loading. The sample was produced using MBF-1002 filler metal. Cracks initiate in the fillet area. The same fracture mode is observed in joints brazed with Au-18Ni, Cocuman, etc.

Thus, brazing undercuts the strength potential of cemented carbide joints.

In order to improve this deficiency, we studied this effect on small standard size superimposed samples. Fig. 7 shows the dimensions of these plates and their relative position. A control sample series was also tested in order to have the reference state with geometry similar to that of the brazed samples. Loading of the brazed samples somehow simulates conditions existing in practical applications, such as very large, expensive oil drill crowns which are subjected to a complex compression/bending mode. As Fig. 7 shows, the plates for brazing and control plates were subjected to the same surface treatments before heating as the single plate samples described previously to separate effects of heating alone and brazing.

Critical fracture strength was measured on two subgroups of brazed samples: one having no fillet formation and others having conventional fillets. In order to manufacture these two groups we used preforms having different dimensions (weights). The fillets formed have equilateral triangular shape with each side being approximately 300-500 μm long. Therefore, cemented carbide adjoining the overlap perimeter is subjected to a stronger erosion beneath the relatively large pools accumulating in fillets rather than cemented carbide beneath the thinner braze. Indeed, braze thickness is normally about 50 - 100 μm. After brazing, some samples were again subjected to the surface treatments in accordance with procedures outlined in Fig. 7. A complete matrix of critical fracture force data for brazements manufactured with MBF-1011 filler metal is superimposed on the treatment flow chart of this figure. Analysis of these data reveals the following trends: a fillet formation on ground-only samples is definitely detrimental (compare 14.08 kN force for K68 sample having brazements without fillets vs. 11.79 kN for the samples having fillets). Sandblasting of such samples and particularly sandblasting followed by polishing recovers the strength. This recovery is similar to the recovery effect observed in heated, single unbrazed K68 plates (compare the first row in Fig. 2 with the first column in Fig. 7).

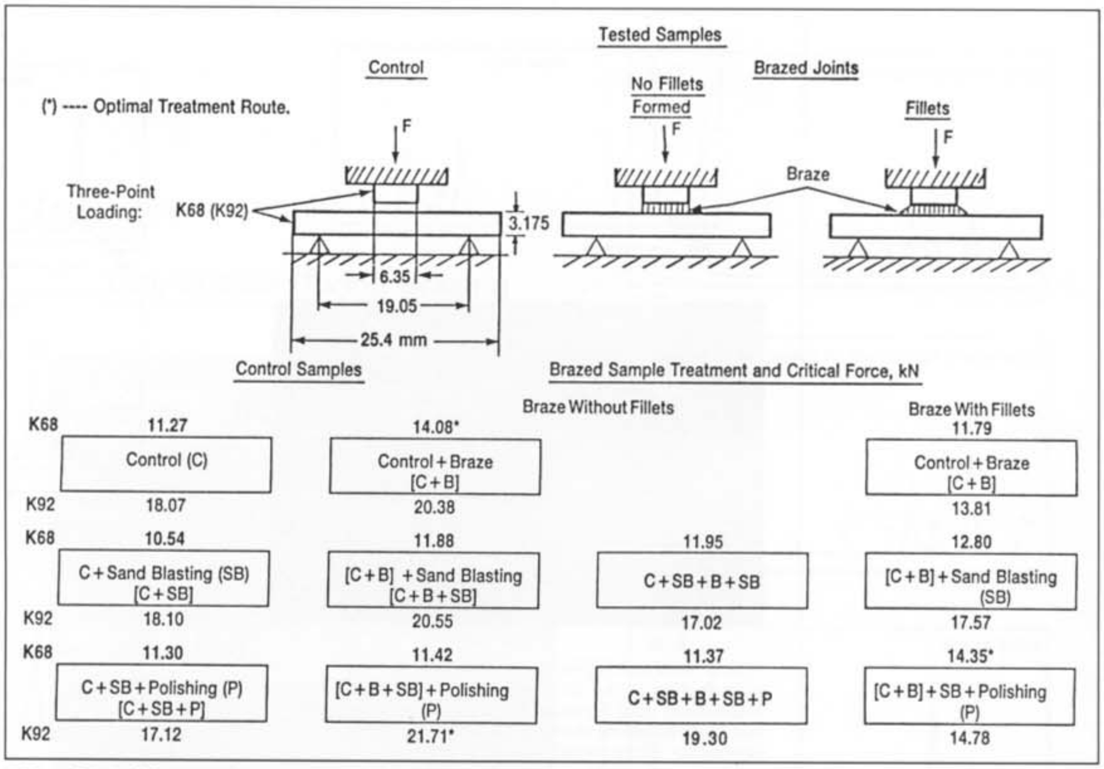


FIG. 7 Critical fracture force of K68 and K92 joints brazed with METGLAS MBF-1011 brazing filler metal.

The same treatments of K92 brazes with fillets results in the opposite effect: the fracture force drops from 19.81 to 14.78 kN. Brazes made from diamond-ground K92 samples and having no fillets display better overall strength, which increases after surface treatment (second column Fig. 8). K92 brazes are also less sensitive to surface treatments than those of K68: K92 contains more cobalt and, therefore, it is more ductile and less sensitive to the crack origination at the surface. At the same time, the surface treatment of K68 'no-fillets' brazements leads to decrease in strength, a reverse of the K92 effect. Finally, additional surface treatment of both K68 and K92 'no-fillets' samples *before* brazing (compare the second and third column in Fig. 7) have lower strength

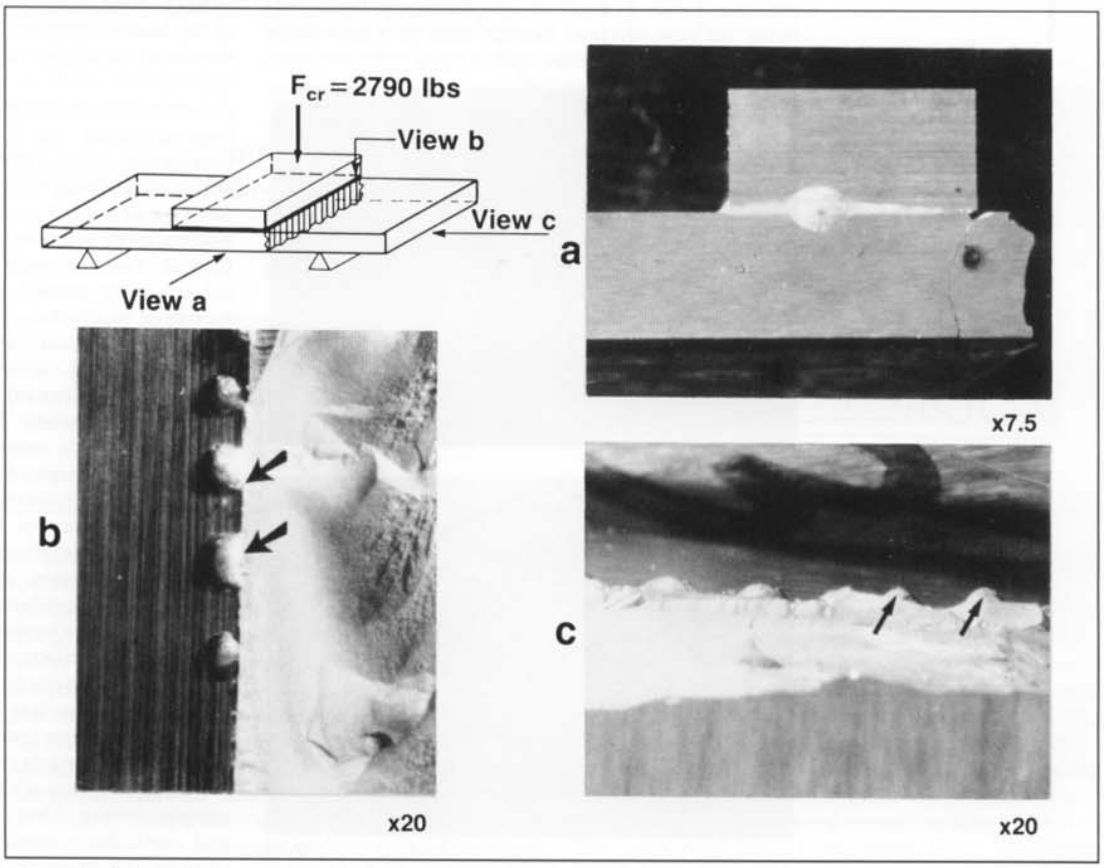


FIG. 8 The fracture face of the K68 joint brazed with METGLAS MBF-1011 filler metal. The brazement was produced with a large brazing gap and excessive fillets. Fracture starts in the excessive drops of the filler metal, which form a part of the large fillet, and proceeds in a brittle mode. Low critical fracture force: cracks are inclined 45° to the brazement plane.

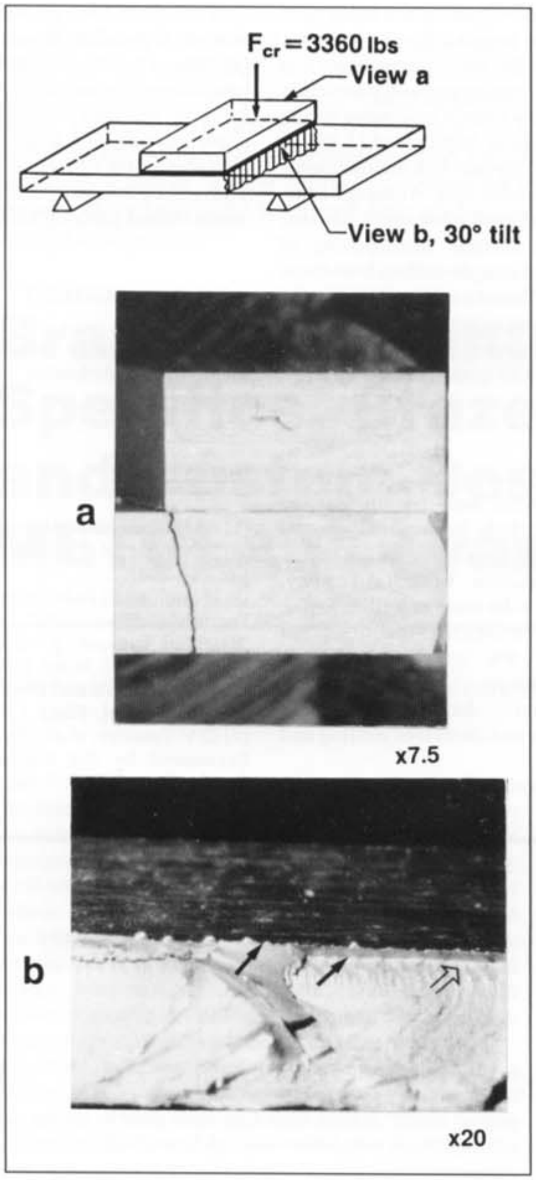


FIG. 9 The fracture face of the K68 joint brazed with METGLAS MBF-1011 filler metal. The brazement was produced with a narrow brazing gap and without fillets. The fracture starts mostly within the brazement perimeter. Some cracks originate in a few small individual drops of the excessive brazing filler metal.

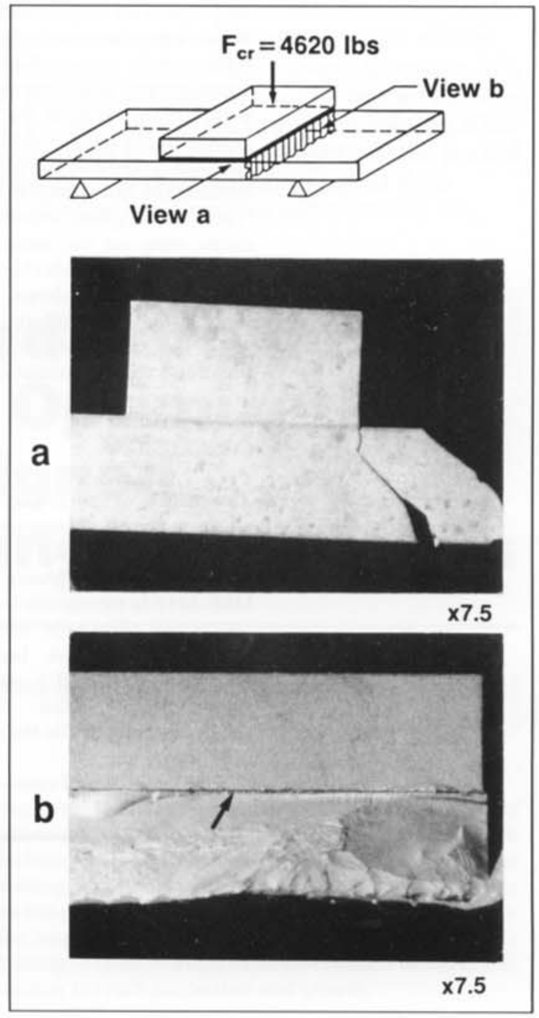


FIG. 10 The fracture face of the K92 joint brazed with METGLAS MBF-1011 filler metal. The brazement was manufactured without fillets and was subjected to sandblasting after brazing. Fracture started completely inside of the base metal. High strength of the brazement is achieved.

than ground only samples. Obviously, diamond grinding is the optimal initial treatment of the sample surface.

It is worth mentioning that even more dramatic strength differences (2-3 times) between brazements with and without fillet is observed on the much larger industrial cylindrical parts. The recovery effect due to surface treatment of brazed parts with fillets is also more substantial than that observed on small plates. The results of this testing will be published elsewhere.

In discussing possible mechanisms for the cemented carbide brazement fracture, one should determine where cracks originated and how they propagate. To begin with, cracks in mechanically loaded cemented carbide initiate in the surface area where the stress gradients are at a maximum. As Fig. 1 shows, even the ground surface of cemented carbide is covered by a pronounced network of grooves. These grooves cover predominantely the places where the cobalt binder is located. They originate during the sintering process as a result of the loss of cobalt at high sintering temperatures. The grooves are the places where cracks are most likely to originate.

The selective erosion of the cemented carbide base metal via cobalt leaching during brazing diminishes brazement performance. This effect is particularly strong in the fillet area. Dissolution of cobalt is followed by filler metal penetration into the body of the base metal via the cobalt-leached network, and by formation of wedge-like inclusions filled by solidified filler metal. Due to a difference in thermal expansion coefficients of cemented carbide and the solidified filler metal, additional stresses occur in the brazement. Therefore, these inclusions function as crack nucleation sites under loading, particularly if they contain brittle intermetallic phases. As our experiments show, cracks originate in fillets if there is no substantial leaching of cobalt and subsequent porosity formation. The large well-defined silicide and boride crystals formed in large fillets of nickel-palladium-base filler metals may be an additional and powerful source of crack initiation. Fig. 8 illustrates crack origination at the top of the large excessive filler metal drops comprising the large fillet. Afterwards, it propagates through the entire body of the sample in a brittle manner. Indeed, the fracture face of this sample has a characteristic glassy appearance.

Large fillets are especially prone to fracture in the case of lap brazements, which are the subject to tensile or bending loads because of the specific stress distributions encountered. As has been shown by finite element analysis, the direction of the shear stress component in the fillet depends on fillet size; in large fillets this component is direted mostly in toward the base metal, part of which is parallel to the braze, whereas shear stress direction rotates more and more toward the brazement plane with a decrease in fillet height (7).

When the same K68/MBF-1011 brazement is manufactured with a narrow brazing gap and practically without fillets (Fig. 9), fracture mostly originates inside of the sample under substantially higher load (3,360 vs 2,790 lbs). The fracture front spreads in a ductile mode, forming the intergranular fracture face. Although some cracks still originate at the surface of a few small, isolated drops seen on the sample surface. Sandblasting of 'no-fillets' brazements rids the sample surface from these small, solidified drops. Therefore, cracks in the sandblasted samples originate completely in the base metal and inside of the brazement perimeter. Fig. 10 illustrates this behaviour in K92 brazements.

CONCLUSIONS

The results of the present work have shown that the performance of cemented carbide brazements may be increased substantially if the following steps are taken:

(1) A new amorphous ductile METGLAS alloy, MBF-1011 is recommended to be used as a filler metal. METGLAS alloy MBF-1011 is nickel-palladium-based alloy containing at least 5% cobalt, about 5% molybdenum and minimum silicon (boron) concentration. The first factor suppresses cobalt-leaching, while the second decreases wetting and fillet formation.

(2) The volume and cross-sectional area of the brazing preform should be optimized in order to minimize fillet size, or, if possible, to eliminate fillet formation.

(3) After completing the brazing operation, it is expedient to sandblast the area adjacent to the braze for 2-3 minutes, followed by light polishing. Sandblasting removes the superficial eroded layer containing crack nuclei, and also eliminates excessive fillet material.

These simple operations increase the critical load for some brazed parts by 100-200%.

ACKNOWLEDGEMENT

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