Chapter IV - Attaching and Assembling Cemented Carbide Parts

In order to take advantage of the unique properties of cemented carbide, such as its outstanding wear-resistance, high level of compressive strength, hardness and rigidity, and at the same time minimizing the consequences of its inherit brittleness, **it is advisable and economically more practical to join the carbide to a tougher material.** Steel as well as other non-ferrous alloys have been widely utilized, thereby forming a composite assembly. By definition, a "composite" product /assembly should be considered to be a macroscopic blend of two or more distinct materials which have a discernible interface between them.

Indeed, by applying intelligent joining techniques, it is possible to get the optimum combination of functional properties at a significantly lower cost for the final product.

In order to achieve compatibility of these opposite materials, a good understanding of the overall physical properties of each material is necessary. A description of the properties of cemented carbide was provided in Chapter II, along with comments and/or a direct comparison to steel.

Attachment of carbide to another mating member of a multifunctional and multilayer assembly may be accomplished by various joining techniques including brazing, industrial adhesives, interference/shrink fit assembly and mechanical fastening. Conventional welding with oxy-acetylene gas or arc welding is a popular joining technique but not in joining carbide to steel. In general, traditional welding can't be considered to be a reliable technological solution because of oxidation issues and the high potential for chemical imbalance (e.g. carbon deficiency). However, recent achievements in vacuum technologies including electron-beam welding have been applied successfully to weld carbide to steel or two carbide components to each other. In addition, " friction welding" has been successfully used in small cross sectional joints, such as carbide tip being attached onto a steel band saw for a metalcutting band saw application.

Both brazing and epoxy adhesive techniques are very common and are used extensively but each has its own inherent limitations, mostly related to their sensitivity to operating temperatures and the presence of corrosive substances in the immediate environment, like sulfur, phosphorus, halides, etc. Interference/shrink fits are very commonly used for cylindrical members since this technique takes advantage of the difference in Coefficient of Thermal Expansion (CTE) of the two materials. Mechanical attachment techniques overcome the limitations of both brazing and epoxy adhesives and tend to make the task easier for replacement of new parts. Interference fits require that the mated sleeves be separated by pushing out the inner carbide insert. Advantages and disadvantages exist with all four techniques and each technique must be judged to be most appropriate for a given application. General Carbide application engineers can recommend which technique is appropriate for any given application.

All four techniques are discussed in detail throughout this chapter.

Brazing

Brazing is a technique to provide a solid joint between two (or sometimes several) dissimilar materials, mainly metal-based materials where the interface is produced by heating of an assembly while utilizing a filler metal. This filler metal compound has a melting point (liquidus temperature) which is substantially below the solidus temperature of the base materials (metals). For metals, brazing is usually accomplished by using a filler metal with a melting temperature above 450°C (840 °F) while another similar process, known as a soldering, employs a filler metal with a melting temperature (liquidus temperature) below 450 °C (840 °F).

During both brazing and soldering, the molten filler metal is distributed by capillary action between the closely fitted surfaces of the two materials to be joined, which then forms a solid interface upon cooling. Due to the physical nature of the brazing process, it is imperative that the filler material has excellent wetting ability (i.e. dihedral angle to be close to zero), meaning that the braze material must adhere evenly and uniformly over the entire surface via capillary action.

Presently, brazing is quite commonly used for cemented carbide in a wide variety of applications and in particular, it has been very successful for small surface areas and shorter length joints. **Common industrial practices for brazing of cemented carbide are furnace brazing, including vacuum brazing and induction brazing, as well as torch brazing and resistance brazing.** Through the use of certain design principles, brazing can also be accomplished satisfactorily on larger joints and long blades. Cemented carbides can be easily wetted with brazing alloys ranging from silver solder to pure copper, which is discussed below.

Bi-metal Thermal Expansion Difference

The Figure IV-1 shows the bi-metal strip effect involved when two dissimilar materials are bonded by fusion of a braze filler material. As mentioned in Chapter III, the Coefficient of Thermal Expansion (CTE) for each material is significantly different, with steel having having a CTE two to three times higher than carbide. At the solidification point of the braze material, the two strips remain straight and parallel. However, as the bonded strips cool, the steel contracts about twice as much as the carbide, causing the bimetal strip to bend as shown. *(Note: curvature may not be representative. When the carbide passes its elastic stress limit, it will crack)*.

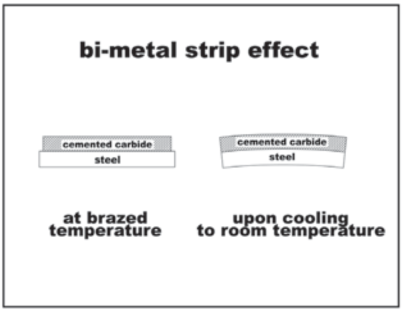

Figure IV-1

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Braze Strain

As the steel base above cools and shrinks, a strain is set up in the joint, the severity of which is dependent on the type of steel and its cooling curve, the grade of carbide and its cooling curve and the type of braze compound. Since the amount of curvature of brazed parts is usually limited by the size of each assembly member as well as the stiffness of the materials within the joint, the strain must be absorbed within the assembly or the strain induced by contraction will be relieved by the carbide experiencing a crack.

Relieving Braze Strains

A simple braze of well-proportioned parts, not excessively long or of large surface area, presents no serious issues when brazing carbide to steel. As a rule, no abnormal strains are observed in the assembly because generated stresses are easily absorbed or relieved by the braze material. However, on longer joints the strain becomes proportionately greater and, therefore, other techniques must be considered. Our extensive industrial experience suggests that braze strains can be relieved by three proven methods:

a) Sandwich Braze – a sandwich braze consists of a copper shim between the carbide and steel parts to be assembled. The copper is not melted because only a low or medium temperature brazing (filler) metal is used. The copper shim is malleable enough to deform under the brazing strain without losing its bond to the steel or carbide parts.

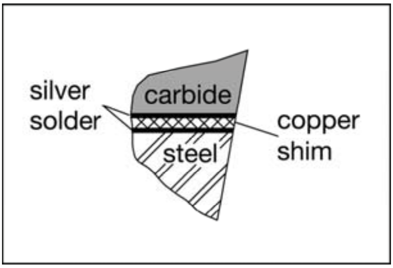

Figure IV-2

The copper shim, as illustrated in Figure IV-2, can also be sandwiched between two shims of silver filler material. 3-ply shims are commercially available with a layer of silver filler material on either side of the copper.

The copper sandwich braze is useful only for light or medium duty since it will tend to "mush" and be squeezed out if the application involves heavy loading or high impact. It will not provide the uniform support required to prevent breakage of the carbide.

A potential alternative is a nickel shim, which will withstand more impact. However, nickel does not have the malleability of copper and will not relieve the braze strains as effectively as copper.

When brazing long joints is unavoidable, counter-straining, peening or soaking process steps are recommended as methods for reducing stress and strain.

b) Counterstraining – This technique utilizes the principle of force and counterforce. By pre-stressing the assembly beyond normal, it is often possible to have the part come out nearly straight when the clamp is removed and the part cools. This pre-stress reduces the tensile stress in the outer edge of a carbide strip by forcibly overcoming the curvature of the assembly. One way of doing this is to clamp the assembly in a jig during cooling. Most of the curvature can be eliminated this way. Fig. IV-3 shows how this principle has been applied to a wear insert.

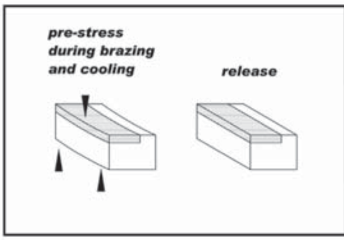

Figure IV-3

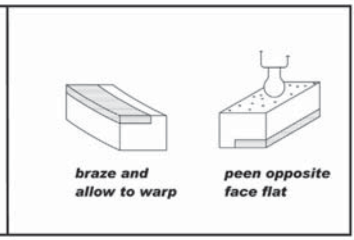

Figure IV-4

Peening is another method of counterstraining and relieving braze stress. This technique is accomplished by using a ball peen hammer peen the steel surface on the opposite side of the braze joint. This will expand it and set up a counterstrain to restore straightness of the assembly (Fig. 4-4).

c) Opposing braze - Another solution to relieve strain is to braze a carbide blade to opposite faces of the steel component. This sets up balanced opposing stresses and an added benefit is that two working surfaces are now available for use. (Fig. 4-5).

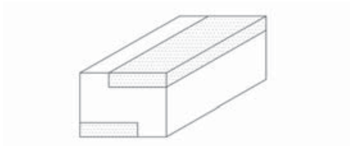

Figure IV-5

With all of these strain-relieving methods, the assembly should be allowed to stand for a few hours (or even days) to allow any residual stresses to relieve themselves. Since the strains may still be locked in, some creep could take place and that must be taken into account before any final grinding of the assembly should occur.

Heat soaking is the process of bringing the assembly to temperatures in the 400°F range and is useful for minor stress relief only. It is not as effective for major stresses that occur in larger joints of 1" or longer because the temperature needed to remove such stresses is 1000°F or above. Since this is just below the temperature at which silver based braze compounds solidify, the cooled assembly would again be strained to about the same temperature after cooling.

Design Recommendations to Avoid Braze Strains

Since braze strains result from the difference in the thermal expansion rates of the materials being brazed, it follows that the use of materials with similar thermal expansion coefficients would result in less braze strains being introduced into the assembly.

Heavy tungsten alloy has a coefficient of thermal expansion approximately equal to that of cemented carbide. The material wets well with silver filler material, producing very sound brazed joints with minimum braze strain. Heavy tungsten alloy has physical properties similar to those of mild steel and is easily machined.

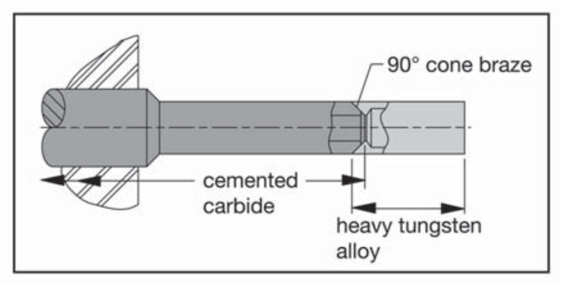

Figure IV-6

If the application being considered can employ heavy tungsten alloy, as depicted above for a grinder spindle housing shown in Figure IV-6, the probability for success is enhanced. The two materials, having similar expansion and contraction curves, will minimize the braze strains in the assembly.

Using a series of short pieces of carbide instead of one larger piece will reduce the cumulative effect of braze strain. An assembly that is designed with joints at non-critical points will avoid strain at highly stressed areas and reduce the likelihood of brazing failure or cracking.

Strains can often be relieved on a mis-proportioned assembly by brazing only on one surface. A special mask-like paint can be applied to the surface on which no attachment is needed so that the braze alloy will not wet those surfaces. A relief gap, machined into the body, will also help to prevent braze material from bonding all surfaces.

A combination of the above principles showing how to reduce braze strains is shown in Fig. IV-7.

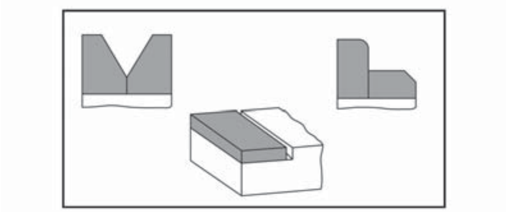

Figure IV-7

Thickness of Braze Joints

The thickness of a braze joint is critical. A thick braze layer can more readily absorb strain but it can fail due to wash out by abrasive action or fail due to peening out by impact loads. It can "mush" due to a lack of strength. For this reason, a thinner braze layer is better because when a braze filler metal compound is stressed, it tends to elongate before failure. This elongation requires a reduction in area. This, in turn, is restrained in the joint by the proximity of the steel and carbide to which the brazing compound is bonded. Thus, the braze compound resists elongation, not only by the shear strength or tensile strength, but by resistance to flow in several directions at once. The result is that the tensile strength of the thin braze can have several times the tensile strength of the braze filler metal used.

A word of caution is needed regarding a braze joint that is too thin. Various tests have shown that going too thin can bond the two materials too tightly and cause cracks in otherwise well-proportioned assemblies. An ideal braze thickness is between .003" and .005".

To assist operators that are unfamiliar with brazing work, it is often helpful to use a prick punch that can be employed to raise an embossed area on the bonding surface of the steel part to approximately .004" height. Three such punch marks will prevent the joint from being squeezed too tightly during brazing and will frequently eliminate braze strain.

Shape of the Braze Joint

For maximum reduction of braze strains, a single brazed surface is best. Some assemblies may not permit this so when more than one surface is to be brazed simultaneously, the design should be such that the carbide will slide along one surface until it engages a second surface. For the situation where three surfaces are involved, the carbide should slide along one surface until it contacts against a second, then move along the two surfaces until it rests against the third surface.

The shape of a brazed joint should be designed so that it will best resist the expected loading when the part is put into operation. For example, a carbide punch in a metalforming application would tend only to encounter axial forces and compressive loading in operation. In this case, a simple butt braze would be sufficient. However, that same carbide tip brazed to steel and used as core rod in a powder compacting application would be subjected to longitudinal forces and lateral thrust, so a conical braze joint would be better in that instance.

Note that conical brazed joints should incorporate a vent-hole to permit exit of gas pockets, flux, or excess braze material which might otherwise become trapped and prevent proper control of braze thickness.

With any of these designs, as the diameters or surface areas increase, so does the braze strain. Keeping the areas to be brazed as small as possible is essential.

Types of Brazing Compounds

The most common brazing compounds for bonding cemented carbide to steel are the silver-copper series, commonly referred to as silver solder alloys. Various other brazing compounds are available for bonding cemented carbide to ferrous alloys and they range from low temperature tin/lead/zinc alloy solders to a high temperature copper brazing filler composition.

Consideration must be given to the temperature range of the application and the bonding temperature of the material when specifying a braze compound for a given job.

Low Temperature Soldering – The lowest temperature solders have the advantage of less thermal strain after bonding but they have low mechanical strength and certainly will not stand up to operating conditions much above room temperature. Bond temperature is only 700°F or lower. This low temperature permits brazing of large areas or long wear strips of cemented carbide and the thermal strains are held to a minimum. Low temp solders of this type contain approximately 40% tin, 35% lead, and 25% zinc.

Medium Temperature Brazing – The silver solder braze compounds are the most common brazing alloys for bonding cemented carbide to steel, as mentioned previously. Silver solder alloys are available in rod form as well as pre-cut shims or strips and typically contain other elements to aid in wetting of the carbide surface. A typical combination of ingredients would be 50% silver with copper, zinc and nickel additives. They are high enough in melting point to be a good choice for the vast majority of wear resistant applications. This material begins to melt at 1170°F and is completely fluid at 1270°F.

High Temperature Brazing – Straight copper is used as a brazing material because it retains practically all of its strength up to a temperature of 1000°F. Beyond this temperature, most cemented carbides begin to oxidize anyway so this alloy will perform at the highest practical operating temperature for most cemented carbides. However, copper brazing requires a hydrogen atmosphere furnace for best results and thus is usually limited to high production operations. It is usually accomplished with pre-cut strips or shim material because the parts are inaccessible during brazing.

Copper makes a good braze as far as bonding is concerned. However, at the 2100°F bonding temperature required to use copper, most common steels will suffer excessive grain growth and, as a result, will be brittle and weak. Some high-speed steels, as well as air-hardening steels or silicon-manganese steels can take these high temperatures without detrimental effects. Other high temperature brazing alloys are composed primarily of nickel and flow at temperatures from approximately 1820°F to 1925°F.

To ensure proper tinning of the surfaces and freedom from inclusions or voids, it is best to heat the assembly well above the fusion point of the filler material. If the designer is unsure which of the above brazing compounds is best for a certain application, please consult the application engineers at General Carbide for recommendations.

Brazing to Hardened Steel

Brazing to hardened steel presents it own unique issues since cemented carbide will not withstand a liquid quench, typically required for hardened steel. Thus, a brazed assembly cannot be subjected to rapid cooling without causing severe cracking. If a very high-hardness steel is desired, an air-hardened steel can be used. It should be brought to recommended hardening temperature and soaked long enough for proper hardening, then air-cooled to obtain hardness prior to any brazing operation. With the steel microstructure properly established, it can be reheated to hardening temperature for a short time, brazed with a suitable brazing alloy for the particular temperature involved and then air cooled. The assembly can then be drawn to the required hardness of the steel without damage.

It is suggested that a nickel base air hardening steel, rather than a chromium base steel, be used because the oxide of chromium that forms on the steel is difficult to flux away. Moreover, nickel steel has higher toughness and, thereby, can better relax stresses generated during the brazing operation. If an intermediate hardness of the steel part is satisfactory, an oil hardening steel can be used, but it must be air quenched to obtain a moderate hardness reading.

High-speed steel can be used for components if hardened, then brazed with a low temperature silver solder at a maximum temperature of 1200°F. The high-speed steel member will retain most of the hardness at this temperature. The resulting combination is suitable for many uses.

Brazing Procedures for Cemented Carbide

Brazing of cemented carbide can be accomplished in any one of several ways, high frequency induction brazing, furnace heating, or torch brazing. Torch brazing of INVAR plugs is described below but in all cases cleanliness of the mating parts is of utmost importance.

Procedure for brazing INVAR plugs in Cemented Carbide for tapped holes:

Turning Plugs:

1. Inspect the hole diameter and the depth/length of the hole.
2. Turn an INVAR plug to .014" - .020" under the hole diameter, or .007" - .010" per side.
3. Cut the plug length .010" over size for counterbored holes, and .025" over for through holes. (You may want to leave more on the length depending on the job and the experience of the operator).
4. If the preformed hole has a radius in the bottom of the counterbore, you will need to radius the base of the plug. You can usually use a file to do this.
5. If the part has through holes, turn the plugs to .020" - .025" under the diameter of the hole.

Preparing the Parts:

1. Grit blast parts using silicon carbide ceramic grit. CAUTION: Aluminum oxide abrasive should not be used since it will inhibit proper wetting of the surface and decrease the bonding strength, especially when brazing flat surfaces together. Silicon carbide is a more friable abrasive and will not penetrate into the micropores of the surface.
2. Wearing rubber gloves, clean all pieces with Denatured Alcohol or Toluene.
3. Be sure the parts are dry.
4. Flux the hole in the part and the plug with Stay-Sylv high-temperature flux. (Fluxing will alleviate air and help capillary action of the braze material to take place).
5. Set parts on a ceramic tray.
6. If the plug is to be inserted into a blind hole, drop small pieces of braze material into the hole and insert the plug. (You can also partially wrap braze material around the plug).
7. In some cases you may have to use a graphite plug to prevent the flow of braze into unwanted areas. For example, a counterbored hole with a through hole being plugged.
8. When brazing flat bars with through holes use a .007" shim on each end of the bar so the plug protrudes.

You are now ready to braze.

Brazing the Parts:

1. Turn on the vapor hood.
2. Cut pieces of braze material to desired length.
3. Heat the part with an oxygen/acetylene torch making sure to heat the part evenly all over. (Take care not to get the part super hot. The torch can reach temperatures up to 1600°F. If heat is not even, the part could crack).
4. Feed the braze material into the gap between the carbide part and the INVAR plug. Also, work the INVAR plug up and down and around to ensure good braze material flow.
5. When brazing carbide parts with counterbored through holes, turn the part over, if possible, and feed the braze material from the bottom.
6. Large mass carbide parts may need to be pre-heated in a furnace to about 1150°F and held there until the part is red/orange in color (approximately one hour per inch of wall thickness).
7. When the carbide part is red/orange in color, remove the parts from the furnace and place them on a pre-heated tray to braze.
8. To prevent the brazed assembly from sticking to the tray when brazing, simply tap it after the braze sets up but while the assembly is still hot.
9. Finer grain grades of cemented carbides need to be staged and preheated to 400°F for about one hour. When brazing is complete, put them back into the preheated furnace at 900° - 1000°F.
10. Turn furnace off and let the assembly cool in the furnace.

Cooling:

1. Let the brazed assembly air cool.
2. Do not set the assembly on a cold surface or expose it to cold air or anything that would cool it rapidly.

Clean-Up and Inspection:

1. Grind off excessive braze material.
2. Grit blast and inspect the assembly to ensure a good braze.

Additional Notes:

1. When brazing round parts it is extremely important to heat the entire part evenly to prevent cracking.
2. Put a piece of steel or graphite inside the I.D. of the part to help hold the heat. Be sure this part has sufficient clearance from the I.D.

Industrial Adhesives

Structural adhesives fall into four broad polymer families: epoxies, cyanoacrylates, silicones and acrylics. With the exception of silicones, these polymers have bond strengths on the order of 2,500 to 7,500 psi in tensile-shear mode. They also tolerate temperature swings as wide as 3500ºF and endure impact loads of 10 ft-lb/in^2 or greater, which demonstrate the advancements that this industry has made in the last 20 years. Industrial adhesives have several major benefits over other joining methods like brazing and mechanical fastenings. Joint stress is reduced by evenly distributing the load over a broad area. Adhesives are invisible because they are applied inside the joint, and they resist flex and vibration stresses by forming a seal that can protect the joint from corrosion.

Adhesives are also a perfect choice for joining irregularly shaped surfaces, which may prove problematic for brazing. Minimal weight is added to an assembly and there is virtually no change in part dimensions or shape.

Some adhesive limitations include a potential need to disassemble the joint, curing time, and surface prep requirements.

Adhesives and mechanical fasteners, when used together, form a stronger bond than when used separately. For example, a bolt that is tightened to the correct torque setting and has a thread-locking adhesive applied to the threads will improve the strength of the assembly. The thread-locking adhesive ensures the assembly will not loosen and corrosion will also be minimized.

Some adhesives require the addition of a hardening agent, often referred to as a catalyst or activator. Others require only heat to obtain the bond. When a catalyst is required, a variable is introduced into the completeness of the mixing. There is a limited pot life, or time during which the epoxy can be applied. In some cases, this can be extended by refrigeration. Most adhesives requiring hardeners have a specified shelf life and the manufacturer should be consulted on their recommendations.

Heat and humidity usually have the most damaging effects on bonded joints, although exposure to solvents and ultraviolet light can also take a toll. Operating temperature is the most important variable that qualifies an adhesive for a particular application. While a device mounted outside is exposed to cold, wet, sunlight, and other conditions, the maximum temperature is not likely to exceed 60°C (140°F). Therefore, an outdoor environment does not eliminate any of the potential adhesive chemistries described above.

Thermal Cycling:
When devices operate in environments that cycle between extremes of heat and/or humidity, they experience thermal cycling or thermal shock. All materials expand when heated and shrink when cooled. This rate of dimensional change is called the coefficient of thermal expansion (CTE) as discussed in Chapter I. Differences in CTE produce stress on the bond joint.

Resistance to thermal cycling is generally achieved in two basic ways:

- A very high strength, rigid adhesive may resist the applied stress. Classic rigid chemistries include acrylics and epoxies, but many urethane modified or elastomer modified formulations are available.
- A softer, more flexible adhesive can absorb the applied stress by flexing or moving rather than cracking. Silicones and urethanes are typical of these softer and more flexible chemistries.

Surface Preparation:
Proper surface preparation is key to ensuring a good bond. It can be as simple as cleaning the surfaces with a solvent to remove oils, greases, and other potential contaminants that could hinder bond strength. Other applications may require surface abrasion or grit blasting to enable proper adhesion. It is our experience that grit blasting alone does not ensure a good bond and chemical cleaning with an approved solvent is recommended.

Adhesive Recommendations:
The most frequent causes of adhesive joint failures do not involve adhesive strength. Typically, adhesive joint failure may be attributed to poor design, inadequate surface preparation, or improper adhesive selection for the substrate and the operational environment. A competent carbide application engineer, familiar with successful assembly techniques will be able to provide the optimum bonding technique for a specific application. Testing under load may be necessary to ensure success of an adhesive assembly.

The joint should be from .003" to .006" in thickness to assure maximum strength in the bond. The facing surfaces must be clean and free from dirt, grease, and scale.

Dozens of adhesives are available for use today. General Carbide has had experience with the products listed below which provide excellent bonding to cemented carbide:

- 3M - DP460, two-part epoxy
- LOCTITE 320 acrylic adhesive with LOCTITE 7075 Activator

Interference/Shrink Fit Assembly

A widely used and highly reliable method of mounting round sections of carbide into steel is to employ an interference fit. The high compressive strength of carbide makes it ideal for the compressive loading encountered with shrink fits and the tensile strength of steel is ideally suited to withstand the hoop stresses encountered with this method.

In a shrink fit design, the amount of interference designed into the assembly depends entirely on the requirements of the application. In heading die applications, the maximum amount of interference and compressive loading is required on the carbide insert in order to overcome the stress reversals that occur when the carbide is subjected to the cyclical loading and pulsating internal pressures of the application. On the other hand, a smaller interference may be adequate in the design of powder metal dies (see guidelines below).

This method of attachment takes advantage of the difference in Coefficient of Thermal Expansion (CTE) of steel and cemented carbide, as discussed previously under Brazing. The difference is in excess of 2 to 1 between steel and carbide and this fact allows for convenient assembly and disassembly of the joint. In applications involving operation at elevated temperatures, the difference in the coefficient of thermal expansion will cause a decrease in the amount of interference and must be considered in the design of the joint. The amount of interference of the shrink fit can be calculated from Lamé's equations. See Figure IV-8.

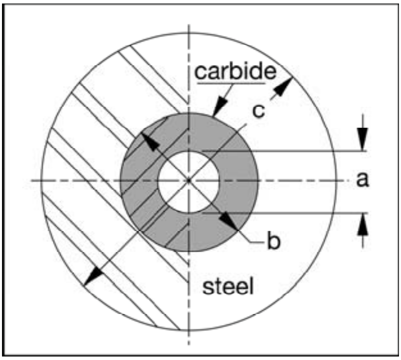

Figure IV-8

where...
δ– diametral interference
P – Pressure between cylinders
E_s – modulus of elasticity of steel
E_c – modulus of elasticity of carbide
μ_s – Poisson's ratio of steel
μ_c – Poisson's ratio of carbide

$$\delta = \frac{bP}{E_s}\left[\frac{b^2+c^2}{c^2-b^2}+\mu_s\right]+\frac{bP}{E_c}\left[\frac{a^2+b^2}{b^2-a^2}+\mu_c\right]$$

If a steel ring is to be shrunk on a solid carbide cylinder instead of a carbide liner, the diametral interference can be calculated by considering "a" to equal zero in the above formula. In Figure IV-8 above, the tangential stress at the inner surface of the steel ring due to shrink is:

$$\sigma_t = \frac{P\,(b^2 + c^2)}{c^2 - b^2}$$

The maximum compressive pre-stress at the inner surface of the carbide, due to shrink, is:

$$\sigma_t = \frac{-2\,Pb^2}{b^2 - a^2}$$

The shrink allowances listed below are general guidelines derived from practical experience. Two levels of interference are shown with each appropriate for different circumstances. Actual calculations with Lamé's formulas above are preferred over the guidelines. Individual calculations should be performed when any new or complex design is employed (i.e., high internal pressure on a die, thin walled cylinder, unusual geometry, or elevated temperature). Consult General Carbide application engineers for guidance.

Shrink Allowance General Guidelines:
Carbide Cylinder Mounted Inside a Steel Ring

OD of Carbide	Low (1) Diametral Interference	Medium (2) Diametral Interference
½" - 1"	.0003"	.0022"
1" - 1 ¼"	.0005"	.0030"
1 ¼" - 1 ½"	.0007"	.0037"
1 ½" - 2"	.0009"	.0045"
2 - 2 ½"	.0012"	.0060"
2 ½"- 3"	.0017"	.0075"
3" - 3 ½"	.0022"	.0090"
3 ½" - 4"	.0027"	.0105"
4" - 5"	.0035"	.0125"
5" - 6"	.0047"	.0155"
6" - 7"	.0055"	.0185"

Low diametral interferences are intended for applications involving low to medium torque and low internal pressures.

Medium diametral interferences are used in applications where the carbide cylinder is subjected to internal pressure. The compressive pre-stress applied to the carbide by the interference fit must be large enough to keep the carbide in compression throughout the working cycle and not allow it to be exposed to tensile stress.

The temperature needed to achieve the assembly fits listed in column (1) of the table above is 450°F. Heat both the carbide and steel parts together. The difference in CTE of the two materials will allow ample time to assemble the joint and to position the two components before the joint sets.

When assembling a heated steel part over a carbide part at room temperature, the steel part loses heat rapidly since the carbide acts as a heat sink. The assembly will set very fast. As mentioned above, it is best to take advantage of the low CTE by sizing the joint for assembly with both parts heated to the shrink temperature. This will allow sufficient time to orient the parts relative to each other before the joint sets. For medium diametral interferences as shown in column (2), it is best to heat only the steel part to achieve maximum clearance between the two rings.

Shrink Allowance Guidelines for PM Dies

OD of Carbide	Shrink Fit for Powder Metal Dies
½"- 1"	.0006 - .0015
1" - 2"	.0015 - .0025
2" - 3"	.0025 - .004
3" - 4"	.004 - .0055
4"- 5"	.0055 - .007
5" - 6"	.007 - .008
6" - 7"	.008 - .0095
7" - 8"	.0095 - .0105

Generally speaking, caution must be taken not to impose maximum interferences in powder metal dies that have various geometries or case materials that range from softer heat-treated steel to harder more brittle materials. Maximum interferences will often split harder cases, thus the guideline above recommends interference fits that fall between the low and medium recommendations in the general guidelines table.

For carbide liners with oval or complex geometry, it is a good idea to contact your supplier for the thermal expansion rate of your specific grade of carbide.

In addition, another important consideration is the scope of the properties of the steel case to be used in the shrink fit assembly. The steel case should have a pre-heat treatment that will retain the mechanical properties of the material, despite any self-tempering and/or self-stress relief that occurs during the shrink assembly procedure.

Shrink Guidelines - Carbide Cylinder Mounted Outside of a Steel Ring:

Normally, tungsten carbide should not be subjected to tensile stress, thus a carbide sleeve shrunk over a steel shaft seems doomed to failure. However, sometimes it is necessary to do so and it can be successful. A complete set of stress calculations must be performed in these cases. Lamè's equations may be used if the subscripts "c" and "s" are reversed. Additional stresses must also be considered. Any operation above room temperature will rapidly increase the tensile stress at the carbide I.D. leading to premature failure. When the carbide is shrunk on the outside of the steel, the designer should use extreme caution and use only the minimum interference necessary.

In summary, if it is necessary to shrink-fit a carbide sleeve onto the outside of a steel shaft, all operating conditions and stresses must be considered. General Carbide's Engineering Department should be consulted when this type of design is desired.

Press Fits – This mounting technique is an interference fit but no temperature is involved. The carbide part is merely forced into the mating steel part by mechanical pressure or force. Light interferences are generally used to permit assembly without biting into the steel wall. Steel requirements are much the same as far as elongation and yield strength are concerned, but the draw temperature is no longer critical. Most tapered dies or pins can be assembled at room temperature. Pressing a pin into the steel recess (Fig. IV-9A and IV-9B) requires a chamfer to properly lead the pin into the hole

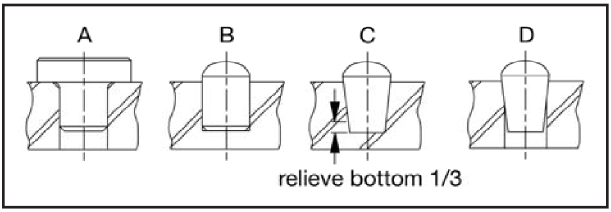

Figure IV-9

In cases where maximum interference is desired and the high temperature required for shrink fitting would adversely affect the hardness of the steel, there is no alternative than to use a heavy interference press fit. In this method, a taper in the range of 1° to 2° included angle, is ground on mating parts so that they can be forced together to give the required radial interference. This technique is used in the multiple ring approach of assembling ultra high-pressure anvils or dies. The tangential stress in each steel ring of the multiple ring anvil design, illustrated in Fig. IV-10, is calculated to approach the yield point of the steel in order to provide maximum support to the anvil. This technique provides greater tensile strength than one large steel ring. The assembly of the part should be accomplished by lubricating all surfaces with a lubricious coating such as molybdenum disulfide or a suitable lubricant.

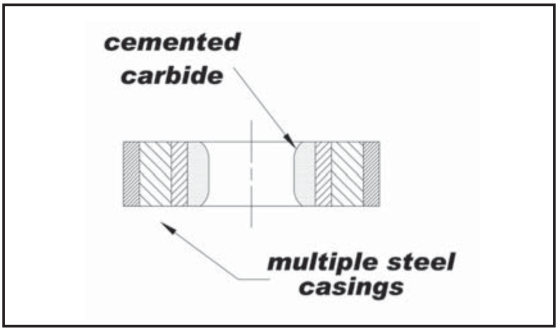

Figure IV-10

Mounting External Rings and Sleeves – In the assembly of some large diameter carbide applications such as rolls or slitters, it is desirable to use external sleeves or rings mounted on steel or a low expansion alloy. In order to avoid hoop stress in the ring or sleeve, the carbide should be mounted by axial clamping as shown in Figures IV-11 through IV-13. In the case of slitter knives, the stresses are principally radial and no positive drive is needed so axial clamping is sufficient. However, in high torsional applications such as drive rolls, a positive drive key is needed. Fig. IV-11 through Fig. IV-13 illustrate proven methods where positive drive is used. Note that a lug should be put on the carbide instead of a keyway put into the carbide. As previously noted, a keyway provides a stress concentration and the drive lug is more dependable. A large radius should be used for the inside corners in Figure IV-11.

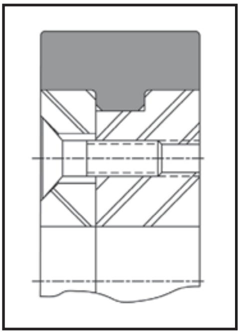

Figure IV-11

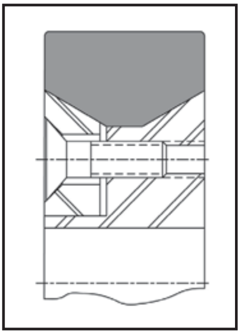

Figure IV-12

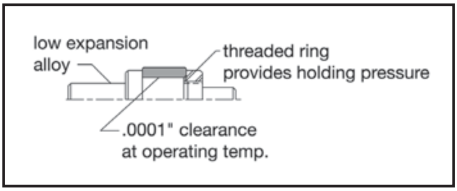

Figure IV-13

Mechanical Fastening

Mechanical fastening represents a proven method for fastening cemented carbide to steel. It cannot be overemphasized that when utilizing mechanical joining, no allowances need to be made for the temperature difference between the thermal expansion rate of carbide and that of the steel holding part or other material used. Even when the temperature range is somewhat wide, and there would be a bimetal strip effect as depicted in Figure IV-1, design modifications can be made to compensate for this effect. Another advantage to be considered is that the steel-based member of the assembly can be hardened and receive the required final surface finish that can be easily matched later on by grinding or polishing of the carbide member of the assembly.

Design Rules For Mechanical Fastening

Certain principles of design should be followed when designing a mechanical mounting for a carbide wear part or component:

a) To maximize support, allow the carbide to rest against a solid surface or shoulder so that the clamping mechanism only has to hold the carbide in place and not resist the direction of the operating thrust of the application. Secure the carbide in a pocket or up against a stop for maximum rigidity and support.

b) A highly polished cemented carbide surface, such as a polished shank on a rotary tool, looks beautiful good but is more difficult to grip than the "as-sintered" surface due to its lower coefficient of friction. The same is true of a working knife-edge where the body of the blade need not be highly polished to allow a clamping device to better secure the blade.

c) Whenever possible, an assembly should be designed to take advantage of the extremely high compressive strength of carbide. Thus, the designer should focus on generating a compressive load on the carbide wherever possible but keeping in mind that notches and keyways should be avoided because they represent (mostly tensile and shearing) stress risers as discussed in Chapter III.

Methods of Mechanical Fastening

A variety of methods can be used to fasten cemented carbide mechanically. Some of the most common are the following:

(a) Clamping – The carbide insert is fitted into a pocket or supporting recess, then held in place by one or more clamps. Fig. IV-14 shows a typical clamp design used for wear parts and machine components. Many other similar variations or designs are used. The key here is to exert uniform pressure over all contact surfaces. All sharp edges nested in the recess should be broken as noted in Chapter III.

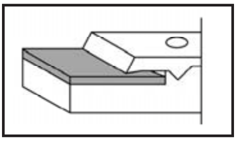

Figure IV-14

(b) **Wedge –** This method is sometimes more practical than clamping if higher pressures are needed to secure the component or if longitudinal movement of the carbide in a slot or recess must be prevented by more than just friction against a clamp. The coefficient of friction of cemented carbide against steel is quite low, therefore, the ability to hold the piece may not be enough to a firm grip by means of friction alone. Wedges can be designed to hold much tighter than clamps. .

Fig. IV-15 illustrates a common type of wedge mounting used today. The strip-type wedge holds a carbide scraper blade by a hex head cap screw inserted into a drilled and tapped hole, placing pressure on the wedge and capturing the carbide in compression mode.

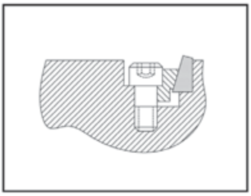

Figure IV-15

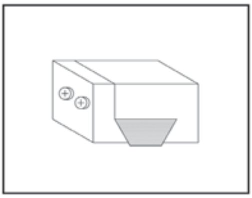

Figure IV-16

(c) **Dovetail –** Dovetail mounting is closely related to wedge mounting and is depicted in Figure IV-16. This technique utilizes the strength of the supporting surfaces to absorb the working stresses while providing a uniform clamping pressure over the entire carbide component. As in all types of mechanical mounting, supplementing rather than opposing the major operating forces is important to the success of the assembly.

(d) **Screw Mounting –** The most practical and economical mechanical attachment technique in use today is screw mounting. This method uses screws to attach carbide to a steel supporting structure and the following figures illustrate the use of countersunk holes with flat head screws. If holes are put in the carbide before sintering, the spacing will vary somewhat but can be held fairly closely per the guidelines noted in Chapter I. In all cases, the hole through the carbide should be oversize, as shown.

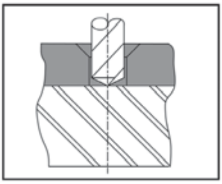

Figure IV-17A

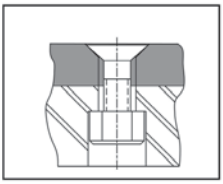

Figure IV-17B

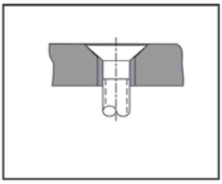

Figure IV-17C

Use the carbide part as a drill jig in order to assure proper alignment of the countersunk holes with the tapped holes in the steel body. An alternate solution to align the holes is to use a nut in an oversize counterbore (such as is shown in Fig. IV-17B). This method permits the screw and nut to float or shift to accommodate variations in the center-to-center distance in the carbide part and is practical on relatively thin carbide strips. It will not weaken the holding power under the screw head.

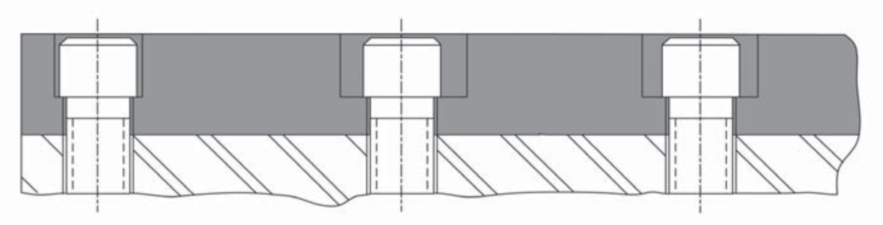

Figure IV-18

Use a counterbored hole to accommodate a heavier screw head when a thicker section of carbide is required. This technique is displayed in Fig. IV-18. All but one of the counterbored holes can be elongated to permit variations in center-to-center distance of the holes. Elongated holes in the mounting body may also be used. Whenever counterbored holes are used, certain precautions are required to eliminate stress concentrations as discussed in Chapter II. (see Figure IV-19).

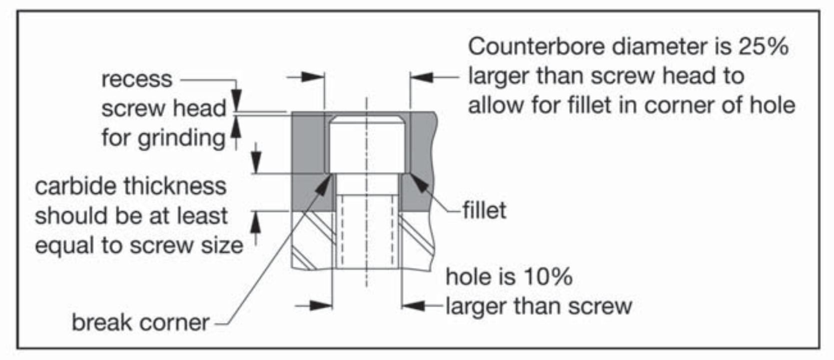

Figure IV-19

Please note the large fillets and broken sharp edges of the carbide. A minor modification in the shape of the part can reduce the stress concentration considerably.

(e) **Draw Rod Mounting** – Assemblies utilizing steel and carbide in which carbide is the integral material of the assembly, such as a pump plunger used in an abrasive pumping application, can be assembled with a draw-rod mounting technique, again employing the carbide in a compression mode. This technique is depicted conceptually in Fig. IV-20.

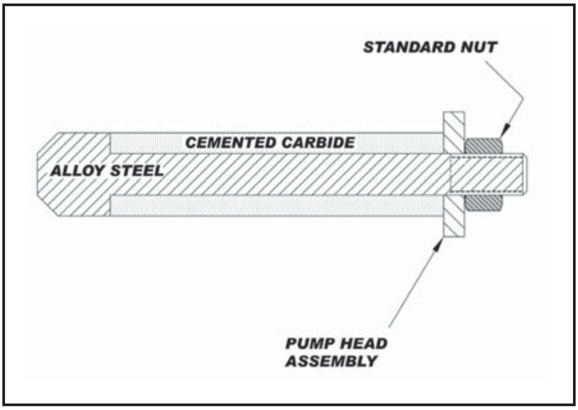

Figure IV-20

The high compressive strength of carbide makes it well suited for the compression loading and the high tensile strength of the steel complements this technique. The steel can be pre-heated and then all parts assembled. Upon cooling, the steel drawrod shrinks and the pre-load is applied axially to the carbide compression member. Please note that the pre-load must be calculated so as not to exceed the yield strength of the steel.

(f) **Tapped Holes –** Tapped holes can be achieved in different ways, either by threading of inserts or plugs or the use of external studs brazed to the non-working surface of the carbide.

A common technique is to use INVAR plugs that can be brazed (see page 34) into a hole previously green machined into the carbide workpiece. Because INVAR has a CTE closer to that of cemented carbide, the resulting assembly is secure through the temperature range of the braze filler metal. The insert is then drilled and threaded to required position and thread size.

If the assembly allows for an external boss, a tapped stud can be brazed to the workpiece. Studs are usually cross-slotted to reduce braze strains. With the advancements in CNC machining, it is possible to put internal threads into cemented carbide in the green state but care must be taken not to over-torque the bolt and strip the carbide threads. Also, calculating shrink factors to ensure the proper hole location is critical when employing this method.

Another technique, developed by General Carbide engineers, is to use a combination of internal carbide threads and epoxy adhesive. In this method, depicted in Figure IV-21, a hole is drilled and internally CNC threaded in the green carbide to an oversize condition of .010" - .014" in diameter from the desired tap size. After sintering, an A2 threaded steel plug is screwed into the hole with high temp epoxy cement. The .005" - .007" gap per side allows room for the epoxy cement to securely fasten the steel insert into the carbide. The carbide is then ready for screw mounting.

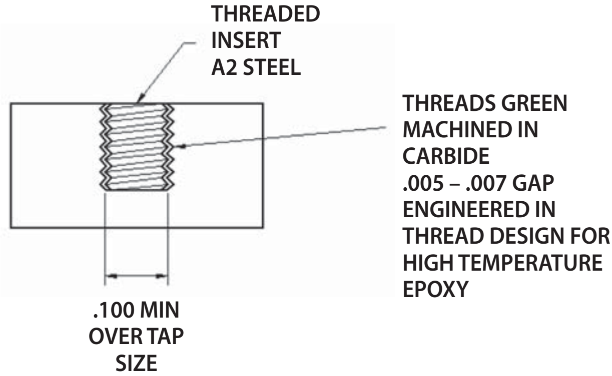

Figure IV-21

This technique offers some advantages over the brazing of INVAR plugs:

- No thermal stress induced by the brazing operation
- Plug can never pull out in service
- Plug can be removed if necessary

Please review the type of internal threads desired with General Carbide application engineers before specifying on a drawing.

(g) **External Threads** – In many assemblies, there is a need for external threads. While threading carbide is possible by hard grinding, it reduces the cross sectional strength due to the notch effect of the threads acting as stress risers. An alternate approach is to braze a thin-walled steel or INVAR bushing in place and thread the bushing.