Powder Injection Molding of Bi-Metal Components

Lye-King Tan and Robin Baumgartner
Advanced Materials Technologies Pte Ltd
100, Jurong East, Street 21
Singapore Technologies Building, Singapore(609602)

Randall M. German
The Pennsylvania State University, PA, USA

ABSTRACT

The method of molding two different materials and sintered them into one complete piece is an attractive and economical mean to integration of different parts using powder injection molding. The paper will illustrate the approach in process developments, problems encountered and the industrial applications. Special attention is required at powder selection and the flexibility in alloying at the feedstock preparation stage. The materials discussed are magnetic stainless steel and non-magnetic stainless steel.

INTRODUCTION

There is a need for objects that contain two parts made of different materials with different properties. Usually all properties of the different materials are similar with one exception. The requirements for such objects could be magnetic properties at one area of the object and non-magnetic properties at another area of the object. Other properties to be altered could be thermal conductivity, electrical conductivity, Young's modulus, hardness, reflectivity and so on. According to prior art, such combination has to be made by welding to join two different parts (Figure 1), or by using a press fit or shrink fit combining two parts, but only if the mechanical stress is not too high. The two parts can be made by conventional metal forming process such as PM, stamping, investment casting, or by more advanced processes such as MIM. However, the addition of a secondary joining operation has several disadvantages. Welding for example produces higher costs and has the disadvantage that a third (weld-) material different from the two others will be added. An obvious improvement over welding or similar approaches is to have the two materials with the different properties sinter to one piece while having contact to each other.

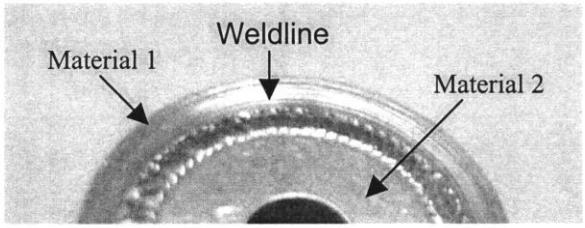

Figure 1: *Bi-Metal Part made by welding*

The ASM Handbook, Powder Metallurgy, Vol 7, page 498, gives the following theoretical information about this: *"Co-molding of different materials is possible, when the materials have either compatible or overlapping process parameters. For example, parts have been made that are double shot in the molding machine so that a portion is a nickel steel while another portion is type 316 stainless steel. After the processing, the part is nonmagnetic and non-heat treatable in the type 316 stainless steel portion and magnetic and heat treatable in the other portion. Many such combinations are possible. The design of double shot mold gating is learned through experience."*

In practice such an approach usually has not been successful because the parts do not properly bond together by forming an integrated microstructure. By a new innovation of AMT we now have the capability to mass produce these two-metal parts, consisting of different components having different physical properties, which can be integrated to form a single continuous body.

Several problems have to be overcome to be able to produce the two metal parts and to manufacture them at reasonable costs and a high yield; such problems are noted in molding, shrinkage, sinter bonding, and other aspects of metallurgical compatibility.

MOLDING

Molding of a two-metal part can be achieved in two ways. At first, one material is injected in one tooling with one or several cavities in a single barrel machine. The molded article is then transferred to another tooling in another single barrel machine, where the second material is injected in or around the first material article (Figure 2). This procedure means logistic and quality problems because the first material article has to be placed exactly into the second mold. This has to be done manually or with the help of expensive automation using robotic arm. Furthermore, the first article material will cool down to room temperature before it is transferred to another injection machine. This will cause thermo-mechanical stress between the two parts after the second molding operation.

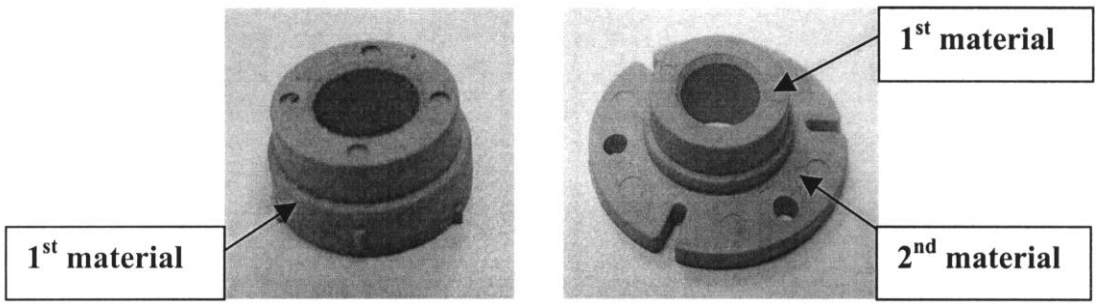

***Figure 2**: First-material molded article (Left) and Two-material molded article (Right)*

A better way is to carry out the molding process on a twin-barrel machine (Figure 3) to mold the complete article within a single tooling. This procedure is already quite common in plastics industry to produce the so-called two color parts.

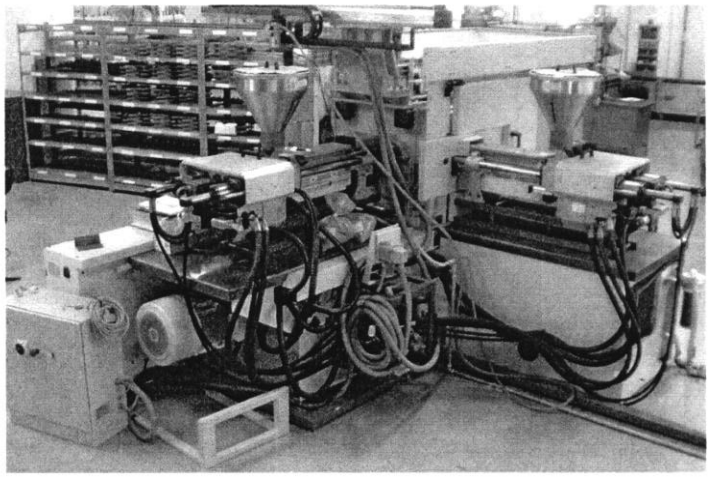

Figure 3: *Twin-barrel machine*

Figure 4 shows how such a two-color part is injected in two steps in one machine using a rotation mold: The insert is injected from one material (step 1) by using the side gate first. Then the whole mold is rotated and the other material (step 2) is injected around the insert. The complete two-color part is removed from the mold. This procedure has several advantages. No handling of the insert is required as the insert is remaining in the mold. The outer material is injected immediately after the insert, so the insert keeps its temperature level. The insert and the outer material cool down together so that there is no thermo-mechanical stress in the parts that could cause cracks. Furthermore, the single two-colour machine takes lesser floor space compared to two injection machines to perform the same task and has the flexibility to run only single-material article alone if necessary.

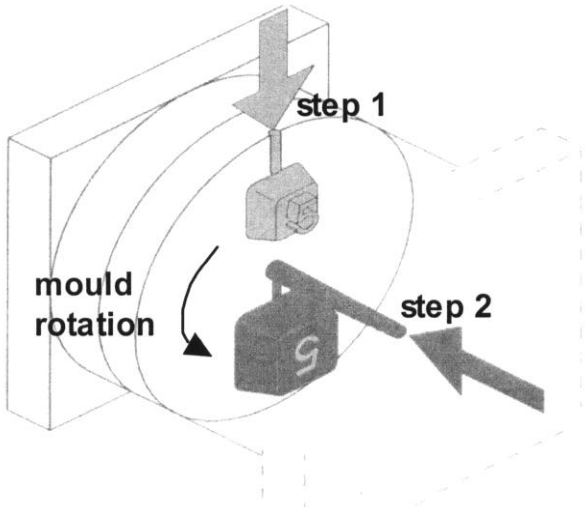

Figure 4: *Molding of two-color plastic parts*

In addition, using a two-color mold is much faster than handling the insert and using two injection machines. Although molding is relatively easy for two-color parts, there are still considerable difficulties with bi-metals by MIM associated with debinding and sintering after molding. Cracking or failure bonding appears, if shrinkage of the two parts differs too much and if certain physical properties differ between the materials.

SHRINKAGE

As already mentioned, proper bonding and parts without cracks can only be achieved by careful control of the shrinkage of the two materials that are to be joined together. Results of successful and poor combinations are shown in Figure 5:

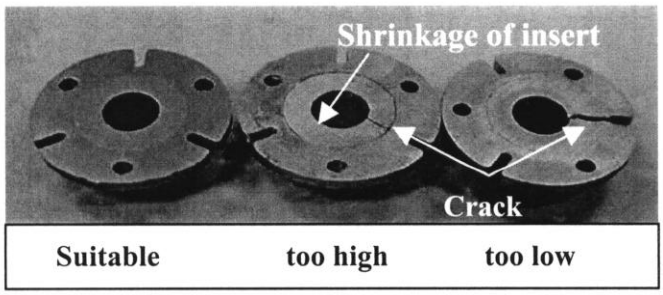

Figure 5: Optimisation of shrinkage

If the shrinkage of the insert is too high, cracks starting at the inner hole appear. Too low shrinkage of the insert does not give enough space for the outside material to shrink, so cracks also appear. It is necessary to adjust the volume loading of the feedstock to give optimal shrinkage for good bonding between two materials. This phenomenon does not depend on the volume loading alone. It is also very important that the powders used to produce the two feedstocks share similar characteristics such as particle shape, texture, size distribution and tap density. If powders from very different alloys are chosen, proper bonding will be very difficult. What happens when choosing different powders are used can also be seen in Figure 6.

In this case a non-magnetic (austenitic) and a magnetic (ferritic) stainless steel were injected using powder A and B with different characteristics (Figure 7). One can easily see the separation of the two materials after sintering in Figure 6(a). On the center side, insert and outer part are made of similar materials (powder B), based on magnetic (ferritic) stainless steel as seen in Figure 6(b). On the right side, a non-magnetic and a magnetic stainless steel were injected using powder B and C of similiar characteristics as seen in Figure 6(c).

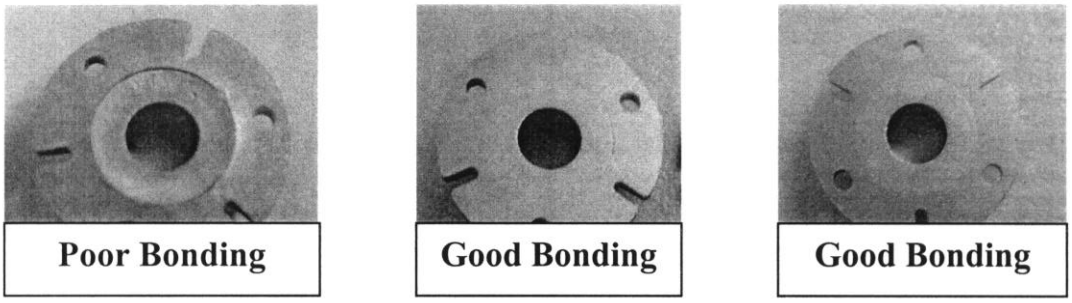

Figure 6(a) Figure 6(b) Figure 6(c)

Figure 6: *Bonding of non-magnetic & magnetic material of different powder characteristics(left), two magnetic materials (center) and non-magnetic & magnetic material of similiar powder characteristics.*

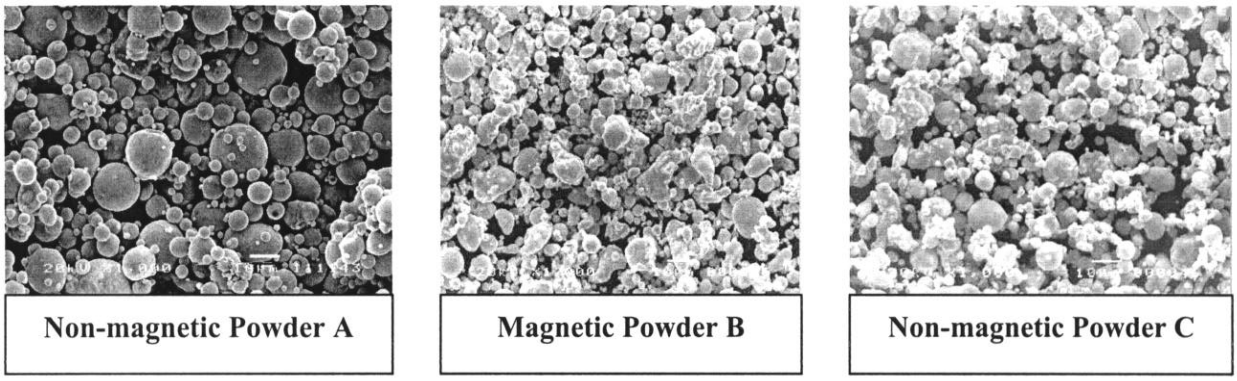

Figure 7: *Micrograph of powder at 1000X*

It can be clearly observed that with careful control of volume loading to manage the shrinkage between the two materials and with similar powder characteristics for two materials, good bonding can occur. The volume loading has to be adjusted in a way that the shrinkage of the contact surface of inner and outer part is about the same, with the tendency that the outer part shrinks slightly more to ensure good bonding. This can be seen on Figure 8, which shows a cross-sectioned bimetal part, polished and etched.

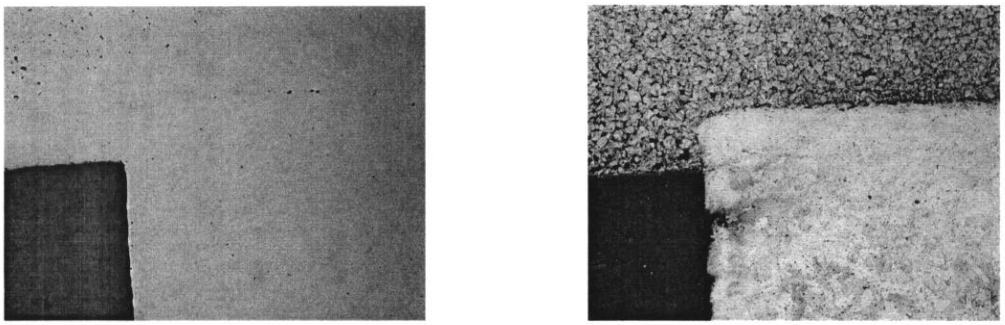

Figure 8: *Cross section of bi-metal part, before and after etching (50x)*

As shown in Figure 6(b) and 6(c), to ensure that most properties of the two powders and most physical properties of the sintered part-sections are similar, except the one that has to be altered, it is useful to make only slight changes in the powder chemical composition.

METALLURGY

Physical properties, which need to be the same or similar if good bonding is to occur are thermal expansion and melting point, while properties that may differ without affecting bonding include electrical conductivity, magnetic coercivity, dielectric constant, thermal conductivity, Young's modulus, hardness and reflectivity.

In those cases that are well suited for the production of bi-metal parts, it will not be necessary for the composition of two powders to vary one from another very much. In fact it is recommended to use the same basic material to fulfil the requirement of similar particle shape, texture, size distribution and tap density to ensure good bonding. Adding only small modifications to the powder, which should be less than 25%, should make the required different properties. This is one of the main advantage of using MIM

technology in producing metallic parts. Few examples of alloying at MIM that have wide industrial applications are Fe-2Ni, Fe-8Ni, Fe-0.8C, etc.

Similar shrinkage and good bonding can be achieved by having the same basic material. During sintering, homogenisation occurs by diffusion of each powder component into the other. Mixed powder homogenisation is most successful with small particles that inherently have short diffusion distances. After sintering with sufficient diffusion, there will be two different alloys, with different properties, within a single component. For example, if a certain area within the part needs to be soft and another section needs to be hard, then using low carbon iron for the soft material and adding a specific amount of carbon in the target hard region is recommended. By doing this, a heat treatment will affect mostly the high carbon region of the part.

Another example is the already shown bi-metal from magnetic and non-magnetic alloys (Figure 9). Obtaining a mixture of magnetic and non-magnetic regions in the same basic material is achieved using an austenitic microstructure in the non-magnetic area and a ferritic microstructure in the magnetic area. The exact amount of each phase is a function of composition and heat treatment. As a different heat treatment is not possible in this case, because the two materials are injected to form one piece, the different microstructures can be achieved by altering the chemical compositions with attention on elements such as chromium, nickel, nitrogen, molybdenum, copper, silicon, and tungsten. The sintering cycle for the production of magnetic and non-magnetic bi-metal parts is shown in Figure 11 while Figure 10 shows the sintering furnace and bi-metal parts.

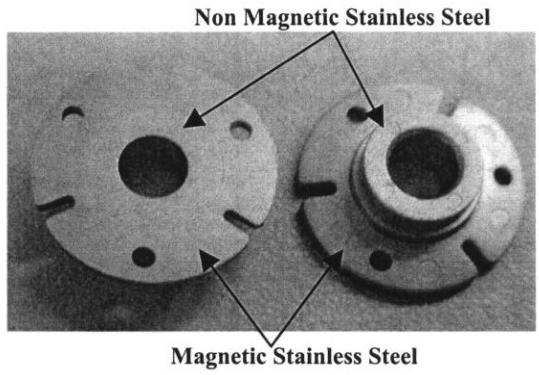

Figure 9: *Example for bi-metal MIM parts: magnetic and non-magnetic*

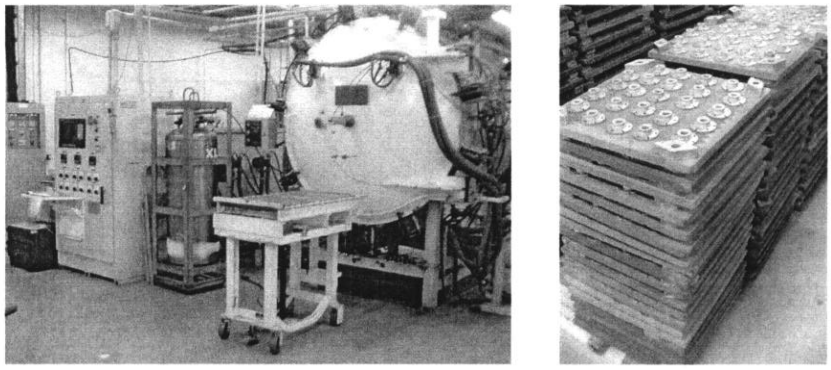

Figure 10: *Sintering furnace and bi-metal parts*

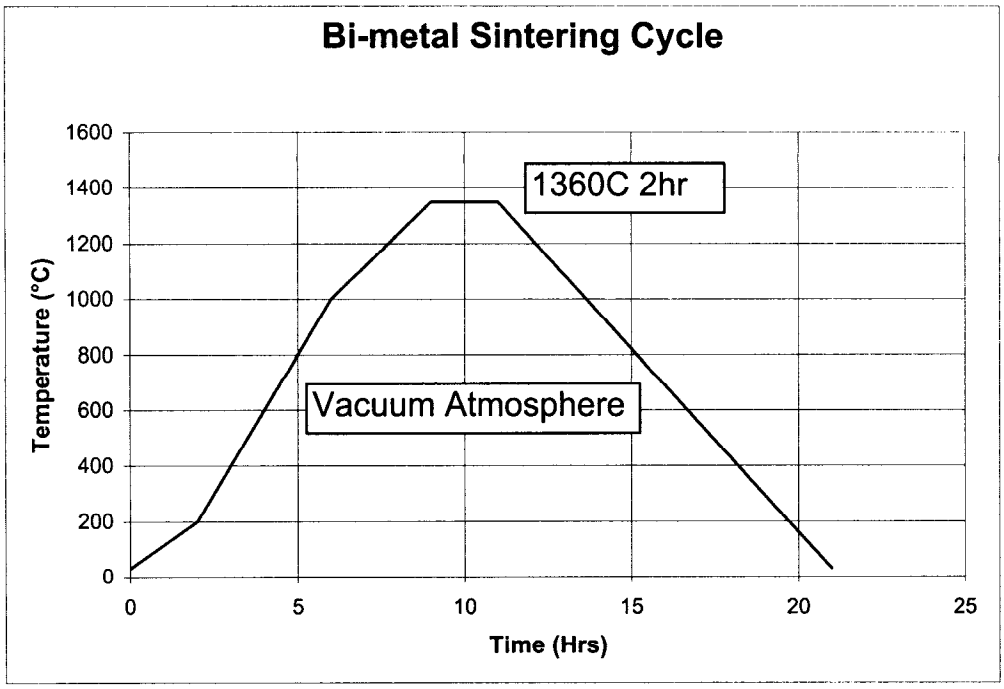

Figure 11: *Typical Sintering Cycle*

SUMMARY

The method of molding two materials and sinter them into one single piece is an attractive and economical mean to integration using powder injection molding. This article shows the various development steps to achieve the capability of producing bi-metal parts from i.e. magnetic and nonmagnetic materials. Problems to be overcome are from metallurgy, powder, shrinkage, bonding and molding.

The most economical means to form such components is via use of a twin barrel molding machine to ensure good quality molded articles. The selection of powder characteristics for both materials is important to proper bonding. The different desired properties can be achieved by making only slight modifications to the powder chemical compositions. The shrinkage has to be carefully adjusted to avoid cracking and to ensure good bonding by fine-tuning the feedstock volume loading. By producing bi-metal parts with MIM technology, the expensive and slow welding process can be eliminated, which results in lower part cost and results in short time to volume production.

Injection molded bi-metal parts also gives better dimensional control, as no distortion from a secondary joining process appears. Having an integrated microstructure within the two materials is the best way of fixing two components together. Co-injection of two different materials to produce bi-metal parts is commercially viable now.

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