TECHNICAL NOTE

Developments in Sintering Injection Moulded PM Parts

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Injection moulding of metal powders holds considerable promise for the development of a new range of highly complex PM components. However, one of the drawbacks of the process is that it takes many hours and even days to remove the binder used to assist moulding of parts, thereby adding to production costs. In the following article Sheldon W. Kennedy of Vacuum Industries Inc, in Somerville, Mass., describes a new one-step binder removal and vacuum sinter process which results not only in much shorter production cycles for a range of parts, but also improves control of carbon levels.

A few years ago it was discovered that small metal parts of very intricate shape could be made by injection moulding. Metal powders are mixed with plastic binder materials and the resulting feedstock is moulded in the same basic technique used in plastic injection moulding. Following moulding, the binder is removed from the matrix of the part and the powder is sintered to form the final article. Excellent repeatability and hence close mechanical tolerances are quite practical.

This technique for manufacturing has been proven to be cost effective for the production of a wide range of parts which otherwise would need to be made by more expensive lost wax casting, machining or assembly of a number of small pieces. However, the utility of the process has been limited and a reduction in both the material cost and the processing cost is desirable to expand the effectiveness of the process to a wider range of parts. The Injectavac furnaces are one of the developments which lower the cost of this attractive process.

BINDER REMOVAL TECHNIQUES

Although the moulding occurs in seconds, removal of the binder and the sintering of the part have taken many hours and even days. This operation has represented one of the higher cost components of the entire production. At first, binder materials were removed by chemical leaching in a very slow but effective process. A second process technique which has successfully removed the binders has been the melting away of the binder materials when the parts are embedded in a fine ceramic powder. The powder acts as a 'wicking' means for removing the binder while supporting the part. This procedure is also rather slow because the total binder material amounts to approximately 40% by volume of the moulded part.

The best practice found up to the present time has been the removal of the binder material by thermal decomposition. This procedure essentially amounts to a burn-out of the binder in an oven, usually with a substantial flow of air to carry off the binder decomposition products and to heavily oxidise the part. After binder burn-out, trays of oxidised parts are placed in an atmosphere-controlled sinter furnace where deoxidation and sintering take place.

All of these older techniques have involved two steps - the removal of the binder and the sintering. The 'vacuum' process that is performed in Injectavac furnaces allows both operations to be performed in a single continuous cycle. Trays containing the parts as moulded are simply placed in the furnace and processed automatically until completed and cooled - ready for unloading and any finishing operations that may be required. No operator attendance is needed and the tender debindered parts are neither handled nor moved for the sintering operation.

PM INJECTION MOULDED PARTS

Figs. 1 - 4 show typical parts that have been manufactured by this process and illustrate the reduction in size that is expected during binder removal and sintering. A test bar is shown both in the green 'as-moulded' state and the completely sintered state when removed from the furnace. The linear shrinkage is in the order of 18-20% in all dimensions, and the exact amount is repeatable with a usual tolerance of 0.003 in. per inch of length (Fig. 1). A small stainless steel insert with internal threads and external ridges was made by MIMTEC for Value Plastics (Fig. 2). A small tungsten carbide slitter knife was produced more accurately by injection moulding than by pressing. Close dimensional control reduced the amount of expensive diamond grinding used as a finishing operation (Fig. 3). A complex bolt lift lever for a sporting rifle made by Kimber had adjoining thick and thin sections. This challenge to the P/M injection moulding process was met and substantial cost savings over previous techniques were realised (Fig. 4).

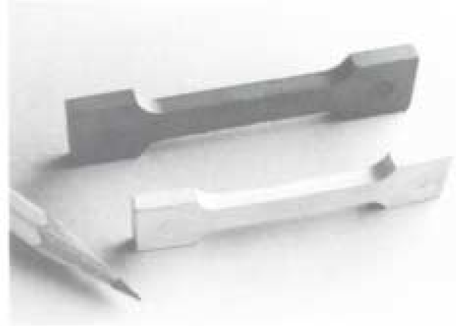

FIG. 1 Injection-moulded medium carbon test bar - as moulded and as sintered. Example of shrinkage expected.

FIG. 2 Stainless steel threaded insert in green and sintered condition.

FIG. 3 Tungsten carbide slitter knife. Moulding and sintering reduces secondary operations.

FIG. 4 Bolt lever for Kimber sporting rifle. Illustration of adjoining thick and thin sections.

PRODUCTION FURNACE OPERATION

A production-size 'Injectavac' furnace with 10

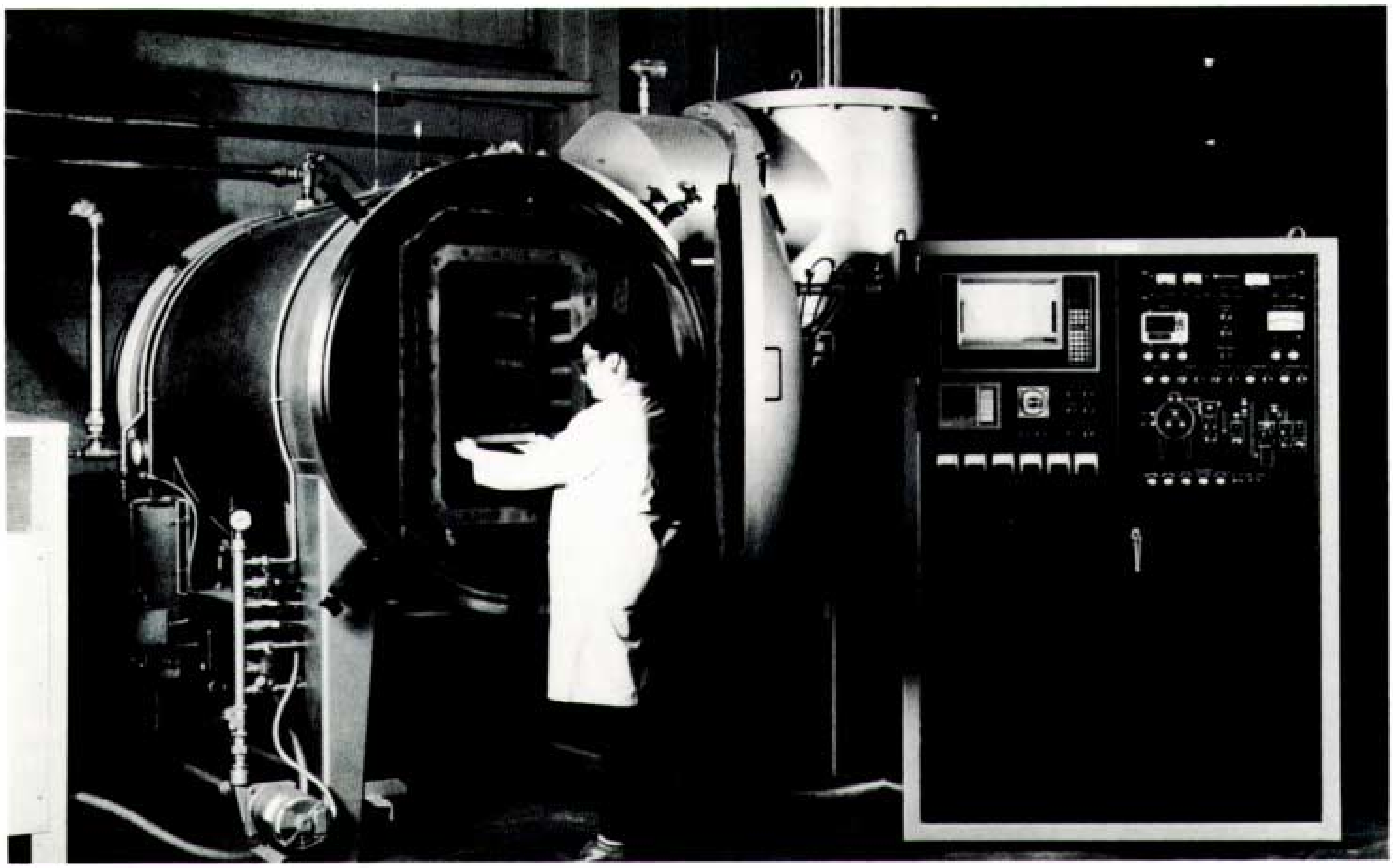

FIG. 5 Injectavac[tm] 500 furnace being loaded.

cubic feet capacity is now available (Fig. 5). The individual parts received from the moulding machine are placed on trays and installed in work boxes. This loading operation may be done while the boxes are installed in the furnace, or the parts may be placed in the work boxes at a separate station and the entire box placed in the furnace.

These furnaces are specialised vacuum furnaces equipped to allow evaporation of binder materials at low pressures, to condense and collect spent binder and to sinter the parts in one continuous cycle. Binders evaporate more readily at low subatmospheric pressure because there are fewer air or gas molecules in the environment to hinder evaporation. The binder vapours released by the work as it is heated are directed towards temperature-controlled surfaces where the spent binder is collected for easy disposal at the conclusion of the run. Following binder removal, the furnace temperature is raised quickly to the sinter temperature appropriate for the material being processed. In addition to temperature, the pressure level, the flow of gases for vapour entrainment and the metal vapour suppression gases are all controlled automatically.

VACUUM PROCESS ADVANTAGES

The vacuum process which has been developed for the production of injection-moulded metal parts has a number of advantages over previous methods:

Shorter Cycle Time

While only a few dozen part configurations have been successfully processed to date, the total cycle time has been no more than one-third the time required to process the same part by any of the older methods. This improvement in processing time appears to be the same for all part configurations regardless of thick or thin sections, varying surface area to volume ratios and alloy composition. Part thicknesses ranging from 0.010in. to 0.600in. have exhibited the same improvement in time for binder removal plus sintering; and the materials that have been successfully processed include nickel-irons of low carbon, nickel-irons of high carbon, 316-L stainless steel, high-speed steel, and tungsten carbide.

Quality

The total environmental control that is inherent in closed vessel processing assures very close control of the final part dimensions, distortion, hardness, incidence of cracks, carbon level and similar parameters. Indeed, the requirements of military QA specs at the 95% confidence level have been met for production lots. Of course, this assumes that the green, as-moulded parts meet this standard before the binder removal and sintering operations.

Carbon Control

The 'vacuum' process enables complete binder removal at temperatures well below the temperatures at which sintering commences with the attendant closing of the interconnecting porosity. Also, neither oxides nor binder residues clog the pores. Therefore, gases which are not harmful to the furnace materials may be introduced in closely controlled amounts and then pumped away after they have done their work on the individual grains of the moulded piece.

By controlling the oxidising potential of some of the binder constituents it has also been found possible to control the carbon content of the part. Decarburisation of the powder can be encouraged, discouraged or nearly prevented if desired. Further, the adjustment of the chemistry of the part is done very rapidly because of the porosity of the piece, thus imposing only an insignificant time penalty upon the entire cycle. For instance, it has been found practical to control the carbon level in 316-L stainless steel to less than 0.01% to enhance its corrosion resistance and also to provide more than 1% carbon for heat treatable steels. Between these two extremes, lots of parts have been produced with the carbon controlled to ± 0.03%.

REQUIREMENTS OF THE VACUUM PROCESS

While the vacuum process that is made possible by the specialised design of 'Injectavac' furnaces appears very attractive with its advantages of a single-step shortened cycle, excellent quality control, and ability to handle thick sections, it imposes certain requirements and limitations at this stage of development:

(1) A batch process is needed to insure complete control of the environment surrounding each piece part at each part of the cycle. The batch size, however, does not appear to influence the total processing time. Therefore, large batches can be processed while maintaining short binder removal and sinter times per piece. For instance, batches of 1,400 pieces of one particular part shape are processed in the production furnace (Fig. 5) in the same cycle time as batches of 60 pieces are processed in a much smaller furnace. The cycle is determined by the time required to remove binder from the piece and the time to sinter the piece rather than by the time for gross removal and condensation of the entire amount of spent binder.

(2) Binder materials must be selected with careful consideration of their removal characteristics as well as their properties most suitable for the moulding operation. Binder materials which break down under vacuum processing into corrosive gases or non-condensable vapours create problems for the vacuum pumping system and should therefore be avoided.

(3) Methods have not yet been worked out for the use of extremely reactive matrix materials such as titanium and zirconium. The sensitivity of these materials to oxygen and hydrogen is well known and their use awaits the development of new binder materials.

FUTURE DEVELOPMENTS

Development of the vacuum process for binder removal and sintering - as well as development of the most efficient furnaces - is in its early stages. Although the improvement in cycle time has been dramatic, further reduction in processing time and, hence, processing costs can be expected in future. Cycles have not yet been optimised. Part design which makes most efficient use of the process as well as the most effective design for the function of the part has not yet been codified. Development of the most appropriate binder materials has also just begun. Progress in these fields is expected to yield substantial increases in the number of parts made by this technique in future years, as well as significant reduction in the part cost.

For truly high production, furnaces with continuous output are needed. Although Vacuum Industries has delivered over fifty such furnaces for such diverse purposes as sintering tantalum anodes, reacting tungsten and uranium with carbon, and sintering tungsten carbide cutting tools, development of continuous furnaces for large quantities of metal injection-moulded parts will require additional equipment development effort. Such effort will, of course, be made when large scale markets justify the work.

Finally, the new advanced ceramics may be made into useful shapes very effectively by the injection moulding process. The binders used for this purpose, however, may require different characteristics from those appropriate for metals because of the difference in the characteristics of the matrix powders. Development work to determine the most appropriate binder removal and sinter cycles is expected to begin in the near future.

SUMMARY

A new, one-step binder removal and sinter process has been developed based upon vacuum techniques. Both laboratory size and production size equipment has been developed in parallel. The result is a much shorter single cycle processing time for a range of parts, as well as good control of carbon levels. As the process, materials and equipment are further developed, a much wider range of cost-effective parts can be expected to appear in the marketplace.