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PM Manufacturing Research Boosted by Continuous Sintering Furnace

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PM manufacturing research boosted by continuous sintering furnace

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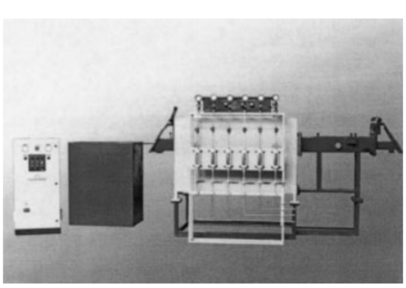
University of Missouri-Rolla has recently acquired a Fluidtherm laboratory continuous sintering furnace. Custom designed and built for PM research, the furnace will allow current efforts in sintering development, pressure gas quenching of PM steels, optimisation of toughness and fatigue properties of PM parts, and production of metal matrix composites to be enhanced and extended.

University of Missouri-Rolla (UMR) has a long tradition of PM research and development. Facilities and equipment are being continually upgraded and added to aid research to improve PM parts manufacturing, alloy development and the properties of sintered parts. Work in the Department of Materials Science and Engineering is targeted at powder characterisation, pressing, hot pressing, powder injection moulding, thermal analysis, ceramics processing, heat treatment, mechanical testing, intelligent control, machining and microstructural characterisation. The present author's more than 20 years of involvement in PM includes work on hard materials, aluminium matrix composites, wear and corrosion resistant PM materials, and CVD and PVD coating using powder as a vapour source. Mechanical alloying has been a particular interest as a means to create unique powders and compositions, including stainless steels, shape memory alloys, intermetallic alloys and hard materials, as has the development of various milling techniques to develop faster, cleaner and more economical methods of powder production.

Recently, Fluidtherm Technology, Chennai, India, donated to UMR a custom compact continuous sintering furnace, designed and built specifically for research in PM. The new equipment will assist research in a number of these areas.



1 *Schematic layout of Fluidtherm pusher sintering furnace, capable of operating at temperatures up to 1400°C in air*

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New sintering furnace

Fluidtherm's continuous sintering furnace (Fig. 1) is equipped with molybdenum disilicide heaters, high alumina refractories and a ceramic muffle, and is capable of operating at temperatures up to 1400°C in air. Any combination of nitrogen, hydrogen, argon and doping hydrocarbon gas can also be used as a sintering atmosphere; all of these gases can be fed from cylinders into a mixing and feed panel.

The furnace incorporates a variable speed pusher mechanism at the charging end and a twin track cooling system at the discharge end. Slow cooling under protective atmosphere is performed in one track and pressure gas quenching – a new system developed by Fluidtherm for which a patent application has been filed – in the second track. This system produces a high cooling rate (approaching 12 K s^{-1}) and can be operated at several levels of cooling intensity.

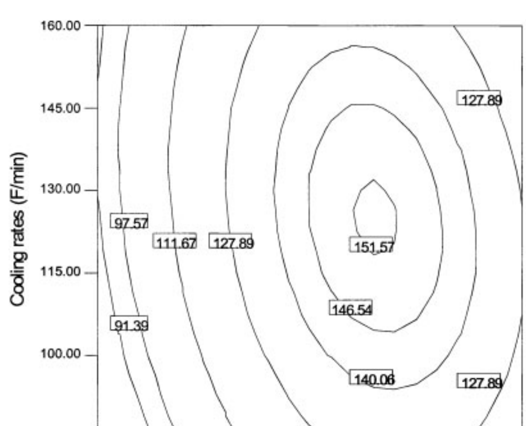
Joe Newkirk (left) with N. Gopinath of FluidTherm

Process control instruments are provided with PC communication for data acquisition and recording. Many industrial cycles can be simulated by controlling pusher speed, preheat or burn-off temperature, hot zone temperature and atmosphere, and cooling zone conditions. The burn-off zone is also designed to perform second stage debinding for injection moulded parts.

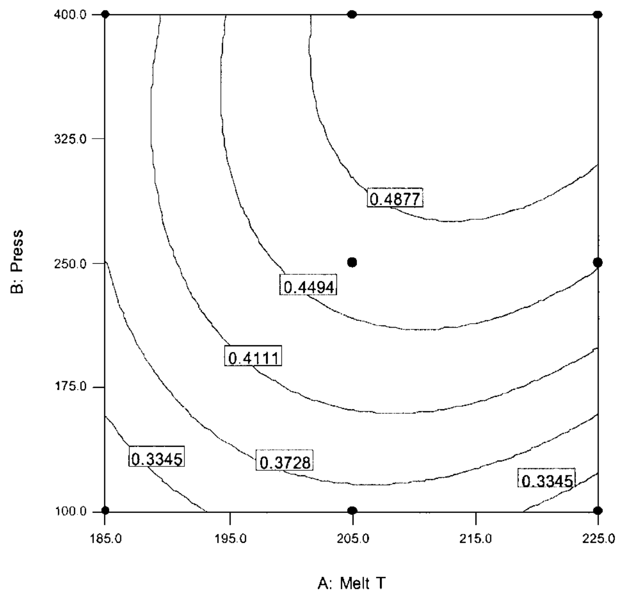
Continuing research

Preliminary plans for using the Fluidtherm furnace include research on sinter hardening, causes of dimensional variation, toughness and fatigue improvement, metal injection moulding, and sintering of metal matrix composites.

The effects of processing parameters on the final properties of



2 *Experimentally determined model prediction plots for UTS sinter hardened FC-0200 steel with varying graphite content and sinter-hardening cooling rate: contours show UTS in ksi (1 ksi≈6·9 MPa, 1 F min^{-1}≈0·55 K min^{-1}). Note that maximum UTS is not at highest graphite content and cooling rate*

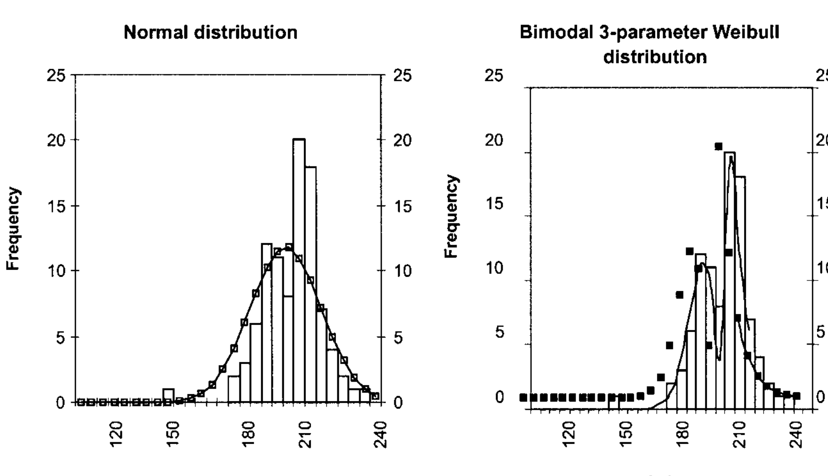


3 *Predicted shrinkage from mould for small metal injection molded part: contours show green part dimensions as percentage of mould dimensions. Note region of low variability (widely spaced contour lines) at high transfer pressure (bar) and high feedstock melt temperature (celsius)*

sinter-hardened PM steels are being studied and process maps have been developed for transverse rupture strength, hardness, carbon level and dimensions of the steels investigated to date (Fig. 2). The new furnace will be used to extend these studies into the variability of mechanical properties. It also will be used to investigate the response of these steels to a pressure quench in place of being fan cooled.

Various composite materials based on aluminium, titanium, nickel and intermetallic matrixes have been fabricated using PM processes. The materials are intended for use in applications requiring high temperature resistance, wear and corrosion resistance and/or high stiffness. In addition, materials with surface layers of aluminium matrix composites are being developed by friction stir processing hard powders into the surface layer.

The effects of metal injection moulding processing parameters on mechanical properties, particularly impact toughness, are being studied. Examination of parts made at several companies to the same nominal specification shows that there can be a large difference in toughness and other properties that are sensitive to changes in microstructure. There is a greater dependence in materials that respond strongly to heat treatment, such as 17–4PH stainless steel. Not only are the average mechanical properties values dependent on processing conditions, but the spread in values for a given set of conditions can also be considerable.



4 *Histograms of transverse rupture strength data from single batch of 96 pressed and sintered FL-4605 steel test bars. Compared with Gaussian distribution (left) most often used to represent mechanical properties data, bimodal three-parameter Weibull distribution (right) shows excellent fit*

Variations can be reduced by choosing regimes where the rates of change in property with processing parameter are greatly reduced.

An additional area of concern for metal injection moulding companies is a lack of understanding of the factors controlling shrinkage as the size and geometry of parts are changed. The ability to predict the relationship between mould size and final part dimensions can pay large dividends in reducing tool rework time and expense. Studies show that the effect of moulding parameters on part shrinkage can be modelled using experimental design techniques. The results predict regions of reduced distortion and lower variability of final dimensions (Fig. 3). Some of these results have already been used by one company to solve a problem with the dimensions of a customer's part. The new furnace offers the capability to continue these studies on the effect of sintering parameters.

The variability of mechanical properties of pressed and sintered PM parts has been studied on a few large data sets. These data sets were generated by mechanical property measurements on large numbers of samples (>60) produced in a single batch using the same processing conditions. For these data sets, the commonly used Gaussian (normal) distribution is compared with the more appropriate Weibull distribution. It can be seen from Fig. 4 that the Gaussian distribution models the actual data inaccurately, particularly at variations from the mean of 3σ and higher. The Weibull distribution models the data better, and also incorporates a threshold parameter that can be used to determine the minimum expected value of a property. In addition, analysis of the data shows that frequently there is more than one maximum in the data, indicating that multiple failure mechanisms are operating.

Friction stir processing is being used to modify the microstructure and composition of alloys, including those produced by PM. Full density and chemical homogeneity can be achieved locally in the stirred region. The research at UMR is aimed at localised modification of components to improve performance economically.

In addition to aiding the projects described above, research planned using the Fluidtherm furnace includes sintering studies, pressure gas quenching of PM steels, optimisation of the toughness and fatigue improvement of PM parts, and production of metal matrix composites. A research consortium involving metal injection moulding, which also will play a major role in educational activities, is also planned.