special feature

DMLS gets an expert once-over

Direct Metal Laser Sintering has real potential for rapid-manufacture applications in the PM arena, reducing lead times and cutting costs. But it has been hampered by the limited range of suitable powders available and their cost. A research group led by Fraunhofer scientists made their own powders and took a closer look...

Of the many laser-based, generative, near-net shape manufacturing processes, Direct Metal Laser Sintering (DMLS) is one of the most suitable rapid prototyping (RP) processes for the direct manufacture of powder-metallurgical components and mould inserts, so-called rapid tools, for plastic injection moulding and metal pressure die casting [1]. A disadvantage of this process is the limited range of materials that can be used. Only three materials based on bronze and steel powders with particle sizes ranging from 20 μm to 50 μm have been commercially available for DMLS processing [2]. These materials are exceptionally expensive.

The parts are susceptible to delamination of the sintered layers and consequent part cracking, particularly when building steel-based moulds [3]. Although this limitation can be overcome by extra effort with data processing, the mechanical and thermal properties of the laser sintered components would be influenced. Additionally, the DMLS parts suffer from low to medium surface quality and dimensional accuracy, which is the inherent weakness of all layer manufacturing processes [4].

The need for development of novel powder materials for DMLS has generated much research work, since the process provides an opportunity to considerably reduce product development time for PM components and hence reduce production costs [5]. A precondition for cost and time savings is that the prototypes, test samples and series components are made of materials having identical properties. The aim is therefore to develop flexible material concepts for different production processes. Pressing and sintering methods are chiefly used for the PM production of large
quantities of work pieces. For these processes, powders can be used which contain coarser particles but which otherwise have identical final properties.

A glance at the literature shows that many researchers have focused on the basic principles of the DMLS process. Some others have focused attention on the application by manufacturing mould inserts for plastic injection moulding and die casting. Comparatively little work has been carried out to link the results of basic research to rapid tooling applications, and it is in this area that a research group drawn from the Fraunhofer IFAM Institute in Bremen, Sharif University of Technology in Tehran and the Federal University of Santa Catarina in Brazil concentrated their efforts.

This research group’s work demonstrates that tailoring the powder particle size is important for the fabrication of full density parts with improved surface quality and dimensional accuracy. The application of findings for manufacturing mould inserts is shown by using a newly developed steel powder mixture, so called LaserTool20. Here, layer thicknesses of 20 μm are used. Thinner layers allow higher sintering kinetics, better dimensional accuracy and improved surface quality.

The characteristics of the iron powders used in the study are reported elsewhere [5]. Two powder categories were used:
- Carbonyl iron powders with slightly different particle size and carbon content.
- Water atomised iron powders with widely different particle sizes. These powders were obtained by sieving. By mixing alloying elements (basically C, Cu, Mo and Ni) with the iron powders, low-alloy steels having the same chemical composition as LaserTool material [6] were produced.

Table 1 summarises the characteristics of the steel powders examined. The LT20A powder is based on the carbonyl iron powder while the others are prepared by blending atomised water and carbonyl iron powders. In the latter case, the composition of the blends was adapted to obtain a mixture with a mean particle size less than 20 μm. This allows powder spreading with a layer thickness of 20 μm. The mixing process was performed in a tumbling mixer for 40 min.

DMLS parts were produced using EOSINT M250 Xtended laser sintering machine (Electro Optical Systems GmbH, Germany). The detail of the machine operation has been explained elsewhere [5]. The laser sintering conditions were: laser power (P) = 100–215 W; scan rate (v) = 50–600 mm s⁻¹; scan line spacing (h) = 0.1–0.4 mm; thickness of layer (d) = 0.05–0.1 mm. The process was performed in nitrogen. The powder bed temperature used was 80°C to prevent the risk of cracking.

The sintered density of the specimens was measured by using the volumetric method. Microstructural evaluations were performed by light microscopy. Samples for metallographic examination were prepared using standard techniques. The hardness of the laser sintered specimens was determined by using Vickers method at a load of 30 kg. The surface roughness of the parts was measured with a UBM VE120 profilometer. Some of the laser-sintered parts were subjected to post-heat treatment or post-sintering according to the procedure explained in [7].

Many tests were performed to develop a novel powder mixture for DMLS. Since powder characteristics have a vital influence on the densification, the role of particle size was first investigated by laser sintering the base iron powders under varying conditions. Figure 2 shows the fractional density of various iron powders with particle sizes ranging from 10 to 200 μm as a function of the ratio of laser power to scan...
These specimens were laser sintered at different laser power and scan rate whilst the scan line spacing was 0.2 mm and the layer thickness was 0.05 mm (Fig. 2a) and 0.2 mm (Fig. 2b). Apart from carbonyl iron powder CL with relatively fine particle size of 10 μm, it is apparent that the densification rate of finer powders is higher than for the coarser ones. In fact, the greater surface area of finer powders leads to higher sintering activity and thereby faster sintering rate. The lower densification of fine powder is attributed to agglomeration and laser scatter. Fine powders are susceptible to powder agglomeration and cause problems during powder recoating. It is known that agglomerated powders have less coupling efficiency under laser [8]. This decreases the working temperature and thus reduces the sintering kinetics. Another consequence of using very fine powder is laser scatter between the solid particles. As the particle size approaches to the wavelength of CO2 laser the solid particles. As the particle size approaches to the wavelength of CO2 laser, it is apparent that the particle size will give higher dimensional accuracy and better surface quality to the laser-sintered specimens. Figure 3 shows the sintered density of the steels made from iron powders LT20A, LT20B and LT20C. The sintered density of LaserTool steel with 50 μm layer thickness (LT50) is included in this graph for comparison. The scan speed of 125 mms⁻¹, scan line spacing of 0.3 mm, and the powder bed temperature of 80 °C were used.

It is important to point out that to make the results comparable all the tests were performed under the same conditions. The results determine that finer powders have higher sintering kinetics and thus get higher final density. It is known that with decreasing layer thickness, the laser energy input and thus the working temperature increases, improving the densification rate. From Figure 3, it can be seen that addition of the water atomised iron powder to the carbonyl iron (LT20B and LT20C) slightly decreases the sintered density. Nevertheless, due to the better flowability of these powders, particularly when higher bed temperature is used, it was concluded that LT20B powder is more usable. Figure 4 shows the surface roughness parameters (Rₐ and Rₜ values) measured from the top surface of the investigated steels. It can be seen that by using finer powders and decreasing the layer thickness, better surface quality can be obtained. LT20B powder has the highest smoothness amongst all. Particle agglomeration during powder recoating is the major problem encountered when finer powders are used. A smooth powder bed without imperfections should be deposited before laser scanning to obtain low surface roughness. Therefore, using bimodal particle size distribution like LT20B blend is useful for DMLS at 20 μm layer thickness. The better flowability of the powder mixture and lower levels of agglomerate formation during the scraper blade deposition are responsible for the smoother surface. Surface quality can be improved further by post-processing such as sand blasting and conventional sintering [6].

The surface quality of laser-sintered parts is also influenced by the scanning strategy. The surface roughness of the laser-sintered specimens was found to be dependent on the layer thickness, laser power and scan speed. The parameter used for changing the scanned layers (usually named "skin") of parts built using DMLS process is a direct consequence of the quality of previous subsequent sintered layers especially when fine layers are used. The parameter used for changing the quality of those layers was the scan line spacing (hatch spacing) due to its great influence on the surface roughness of a single layer. Figure 5 shows this effect for the steels made by laser sintering at 20 μm layer thickness. It is apparent that there is an optimum overlapping value between scan lines, where minimum surface roughness is obtained. The optimum condition is material-dependent, i.e. there is no unique optimum line spacing for the materials examined. The smoothest surface is obtained at hatch spacing of 0.2 mm for LT20B powder.

As reported previously [9], the microstructure of LT50 powder is very heterogeneous with different phases including ferrite, bainite, martensite or transferred martensite. A more homogeneous microstructure was obtained when LT20B powder was laser-sintered. This is attributed to the finer powder particles being deposited in smaller layers before laser scanning. The surface microstructure of the LT50 powder is very different from that of the LT20B powder, which is more homogeneous with a fine lamellar structure. This indicates that there is a close relationship between the densification, the processing parameters, and the powder characteristics.

Laser sintering of steel powders with the characteristics given in Table 1 was looked at to study the effect of using lower layer thickness - 20 μm - on the densification. It is expected that lower layer thickness will give higher dimensional accuracy and better surface quality to the laser-sintered specimens. Figure 3 shows the sintered density of the steels made from iron powders LT20A, LT20B and LT20C. The sintered density of LaserTool steel with 50 μm layer thickness (LT50) is included in this graph for comparison. The scan speed of 125 mms⁻¹, scan line spacing of 0.3 mm, and the powder bed temperature of 80 °C were used.

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<table>
<thead>
<tr>
<th>Property</th>
<th>Laser-sintered</th>
<th>Post-sintered</th>
<th>Heat-treated</th>
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<td>&gt;99</td>
<td>&gt;99</td>
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<td>850</td>
<td>450-1200</td>
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<td>Hardness, HV30</td>
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<td>300-800</td>
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Table 2. Density and metal matrix hardness of the laser sintered iron powders

Figure 4. Surface roughness of laser-sintered steel powders

Figure 3. Sintered density of the examined steel powders. Laser power of 200 W, scan rate of 125mm s⁻¹, scan line spacing of 0.3mm and bed temperature of 80°C were applied.
used and lower layer thickness applied. Increasing the laser energy input enhances the working temperature, leading to better material homogenising during liquid phase sintering.

On the other hand, finer particles provide less of a transport path for the alloying elements to be dissolved and homogenised - another advantage of using finer powders.

Figure 6 shows a picture of a mould insert produced from LT20B powder at a layer thickness of 20 μm. In highly demanding applications like tooling for injection moulding or pressure die casting, subsequent steps of post sintering and heat treatment can also be used to create fully dense steel parts with tailored and improved final properties.

The Authors

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References


