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Laser additive manufacturing of gas permeable structures

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Abstract

Laser additive manufacturing offers a variety of new design possibilities. In mold making laser additive manufactured inserts with conformal cooling channels are already state of the art. Pneumatic ejectors for injection molds are a new application for laser additive manufacturing. The pneumatic ejectors require a durable gas permeable material. This material is produced by placing the scan vectors for the laser additive manufacturing process in a defined pattern. Trials with different plastics proofed the function and reliability of the pneumatic ejector concept in the injection molding cycle.

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Keywords: Laser Additive Manufacturing; Gas Permeable Material; Injection Molding

1. Pneumatic ejectors for injection molds

The plastics processing industry is an important economic branch. In 2010 a total revenue of 51.3 Billion € was generated by this industry in Germany. Injection molding is the major manufacturing processes for plastics (GKV, 2011). Injection molds are made of tooling steel as individual parts or in small lot sizes. Tool manufacturers are under a high time and cost pressure due to competitors from low wage countries. At the same time their customers are demanding high quality and short time-to-market. Since injection molds are produced in small lot sizes, there is little potential for automating the production process. The savings potential of automation is already exhausted.

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A system with a high impact on costs and lead time in mold manufacturing and high maintenance costs in operation is the ejector system. Fig. 1 shows the ejection process of a mold with a conventional mechanical ejector system. Molten plastic is injected into the mold. It is cooled down and solidifies in the mold. The part shrinks onto one half of the mold. In Fig. 1(a) the plastic part will stick to the movable left half of the mold. Once the material is solidified the mold opens and ejector pins push the part off the mold as seen in Fig. 1(b). (Feldhaus, 1993; Menges et al., 2007)

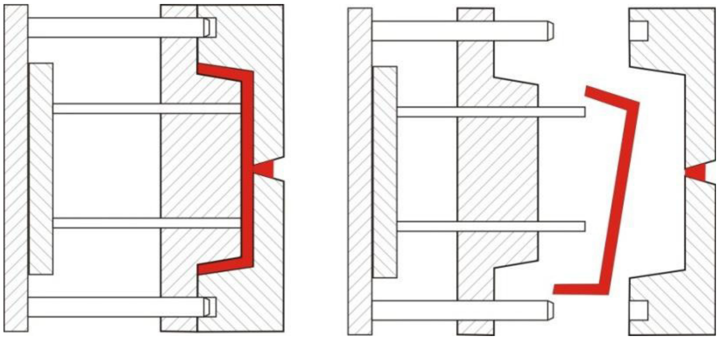

Fig. 1. Injection mold with mechanical ejectors during cooling phase (a) and ejection process (b)

The mold in Fig. 1 is a simplified representation of a real mold. In most injection molds the ejector system is quite complex. Many ejector pins are required to push the part out. The length of the pins has to be within a very narrow tolerance; otherwise the ejectors will leave marks on the surface of the part. Same applies to the diameters of pins and holes. Is the gap between pin and hole to tight, the pin gets stuck and damages the mold. Is the gap to wide melt enters and the quality of the part is reduced. All of this results in tight tolerances and therefore a costly ejector system with a long lead time. (Menges et al., 2007)

A new way to save time and costs on the mold and improve the quality of the plastic part is the replacement of the mechanical ejector system by a pneumatic ejector system. The system is integrated into a laser additive manufactured mold insert together with the cooling channels. Fig. 2 shows the setup of such a system. Within the insert pressurized air is transported close to the surface of the mold by air supply channels. A top layer of about 5mm is made of gas permeable material. The openings in the material have to be wide enough to allow a sufficient air stream from the supply channels to the surface, but narrow enough to keep the melt from entering.

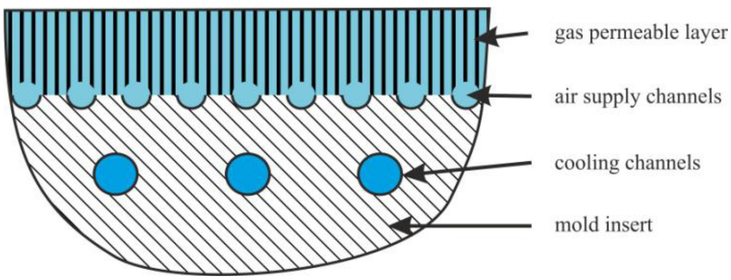

Fig. 2. Mold insert with cooling channels and a pneumatic ejector system

2. Structure of the gas permeable material

A highly complex part, like an insert with the pneumatic ejector system shown in Fig. 2, cannot be manufactured with conventional methods. To produce inserts with a pneumatic ejector system laser additive manufacturing is used. Laser additive manufacturing is a cyclic process to manufacture arbitrary formed parts out of metal powder. The production cycle consists of applying a thin layer of powder, melting selected areas of the powder bed with a laser beam and lowering the building platform by the layer thickness of 30µm to 45µm to bring part and powder bed in position for the next cycle. Following this process freeform parts are built up layer by layer out of powder. A variety of metals is available as powder materials. This includes Aluminum and Titanium alloys as well as stainless steel and tooling steel. The most common material for laser additive manufacturing of molds is tooling steel 1.2709. (Over, 2003)

Laser additive manufacturing of metals has opened new possibilities in design and function over the last years. In mold making laser additive manufactured inserts are already used in injection molds. The freedom of design allows mold manufacturers to design injection molds with better temperature control using contour following cooling channels (Vogel et al., 2007). One of the key goals of laser additive manufacturing in mold manufacturing and other applications is to achieve a density of 100%. The properties of laser additive manufactured material are linked to the density. The strength and hardness of laser additive manufactured parts without pores is similar to the strength of solid material. (Yasa et al., 2010)

A different approach is the use of lower density areas to create new functions. In mold design inserts with low density have been investigated to vent air from the cavity through porous materials. The conventional way of building porous material is by altering scan speed and hatch distance (Trenke, 2006). This results in a material with sufficient permeability, but also with a lot of unconnected pores as shown in Fig. 3. These pores weaken the material without contributing to the permeability (Stoffregen et al., 2011). Since the scan vectors are placed without respect to previous or following layers, the size of the openings at the surface varies. This leads to a rough mold surface which results in a poor quality of the molded part. Some openings are even big enough for melt to enter into the pneumatic ejector system. In the best case the melt solidifies in the opening and clogs it. At worst it passes one of the micro channels of the gas permeable layer into the air supply channel. This leads to the failure of the ejector system. To produce a durable material with a high permeability for gases, a better control of the structure of the gas permeable material is necessary.

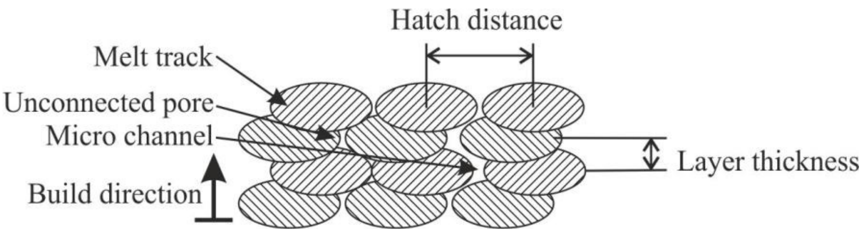

Fig. 3. Structure of laser additive manufactured material with increased hatch distance

A different technique is developed for permeable mold inserts, because they need to provide a high air flow through the layers and require a high surface quality. This is archived by varying the scan strategy for the gas permeable layer of the mold insert. The part is built up as shown in Fig. 4. The melt tracks are placed on top of each other. The stacked melt tracks form walls with the length of the scan vectors. The micro channels between the tracks are straight in building direction and along the scan direction. Within the walls the structure is free of unconnected pores.

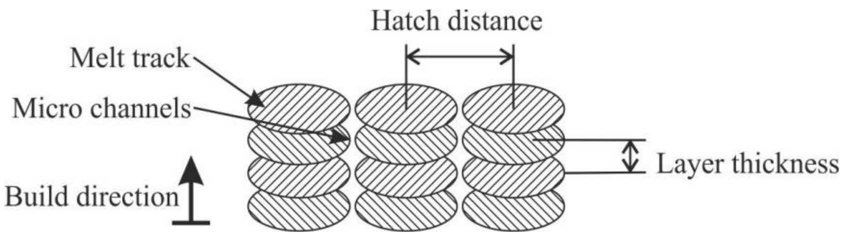

Fig. 4. Improved structure of laser additive manufactured material for high air flow through the layers

The length of the scan vectors is limited by three influences. Shorter scan vectors decrease the area of the gaps. The air flow and with it the performance of the system is reduced by this. A long scan vector leads to high residual stress within the melt track and the distortion of the structure. A second limit comes from the application in injection molds. The melt is injected into the mold with high pressure and high velocity. If the scan vectors are too long, the walls become too flexible. The melt flow puts a lateral force on the tip of the wall and opens the micro channel. Some melt enters the channel; this increases the contact area of the melt on the wall. The injection pressure is applied on a larger area and the lateral force increases. As a result the deflection of the wall grows, the gap widens and more melt enters. This self-amplifying process leads to the destruction of the mold insert. To give the gas permeable material the required stability, the area for the pneumatic ejector system is segmented in smaller areas. The scan vectors are arranged in a way in which the walls support each other. Fig. 5 shows such a segmented structure. Each checkerboard square consists of parallel walls. The orientation of the walls in one square is perpendicular to the ones in the neighboring field. The melt tracks end in the first track of adjacent field. In this layout the ends are fixed and the structure is strong enough to withstand the forces of the injection process.

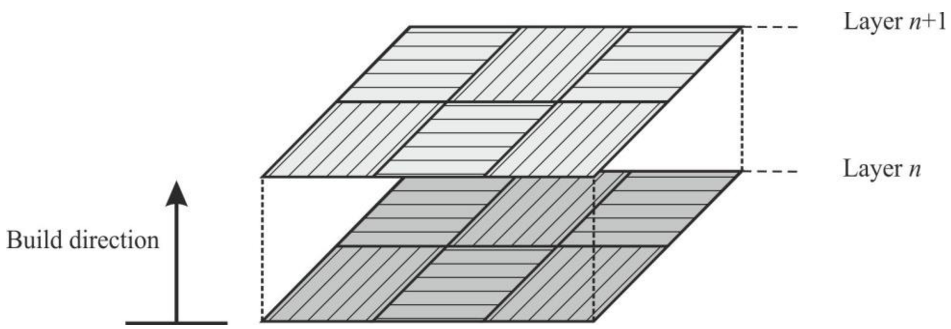

Fig. 5. Improved structure of laser additive manufactured material for high air flow through the layers

3. Experimental

To test the structure described in the previous section different samples were produced on a ConceptLaser M2 Cusing machine with a 200W laser. The gas permeable layer is an integrated part of the mold insert. It is built up together with the rest of the insert in one laser additive manufacturing process. Therefor the layer thickness of 30µm is set for the gas permeable layer and the rest of the insert.

Laser power and scan speed need to be adjusted, because the gap between the walls acts as a heat insolation. In conventional laser additive manufacturing the melt of one track is drawn to the neighboring track and has a solid body underneath. Both stabilize the melt pool and act as a heat sink (Yadroitsev et al., 2010 (a), Yadroitsev et al., (b)). The heat is quickly transported away from the melt pool and into the part. In the gas permeable material the only connection to solid material is through the wall underneath the melt pool. This results in a low heat conduction away from the melt pool. The energy input in the melt pool needs to be reduced to compensate for this.

To process tooling steel (1.2709) powder into solid parts by laser additive manufactured a laser power of 180W, scan speed of 600mm/s and a hatch distance of 105µm is needed. This set of parameters enters too much energy into the melt pool. The amount of melt is increased and leads to an unstable process. A known structure, which is also built by adding single tracks on top of each other, are supports. The supports are built with a laser power of 120W and a scan speed of 800mm/s. To identify the proper hatch distance for the production of gas permeable material for pneumatic ejector system a number of samples with hatch distances between 120µm and 200µm were built-up.

Inspection of the samples shows an average melt track width of 85.9µm. The samples with hatch distances above 140µm have a continuous gap between the walls. There are hardly any connections between the walls. This is shown in Fig. 6(b) on the example of the structure with 170µm hatch distance. The sample with a hatch distance of 120µm in Fig. 6(a) shows a different kind of structure. The walls are not separated by a gap. Instead rows of large pores with an irregular shape indicate the position of the space between melt tracks. A hatch distance of 120µm is not wide enough to create the desired structure as shown in Fig. 4.

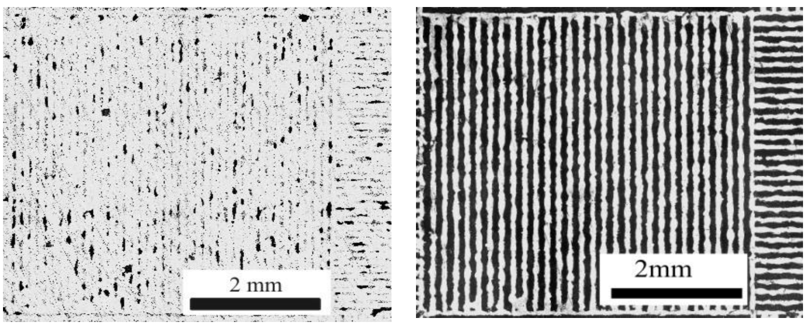

Fig. 6. Structure of gas permeable material with 120µm hatch distance (a) and 170µm hatch distance (b), view in build direction

The permeability of the samples is tested with pressurized air on a test bench. The test setup records air flow and pressure before and after the sample. Fig. 7 shows the gas flow over the difference pressure of a set of six samples 19mm x 38mm with a thickness of 10mm. All samples show a linear relationship between pressure difference and air flow. A hatch distance of 120µm does not provide a significant air flow. This confirms the result of the visual inspection.

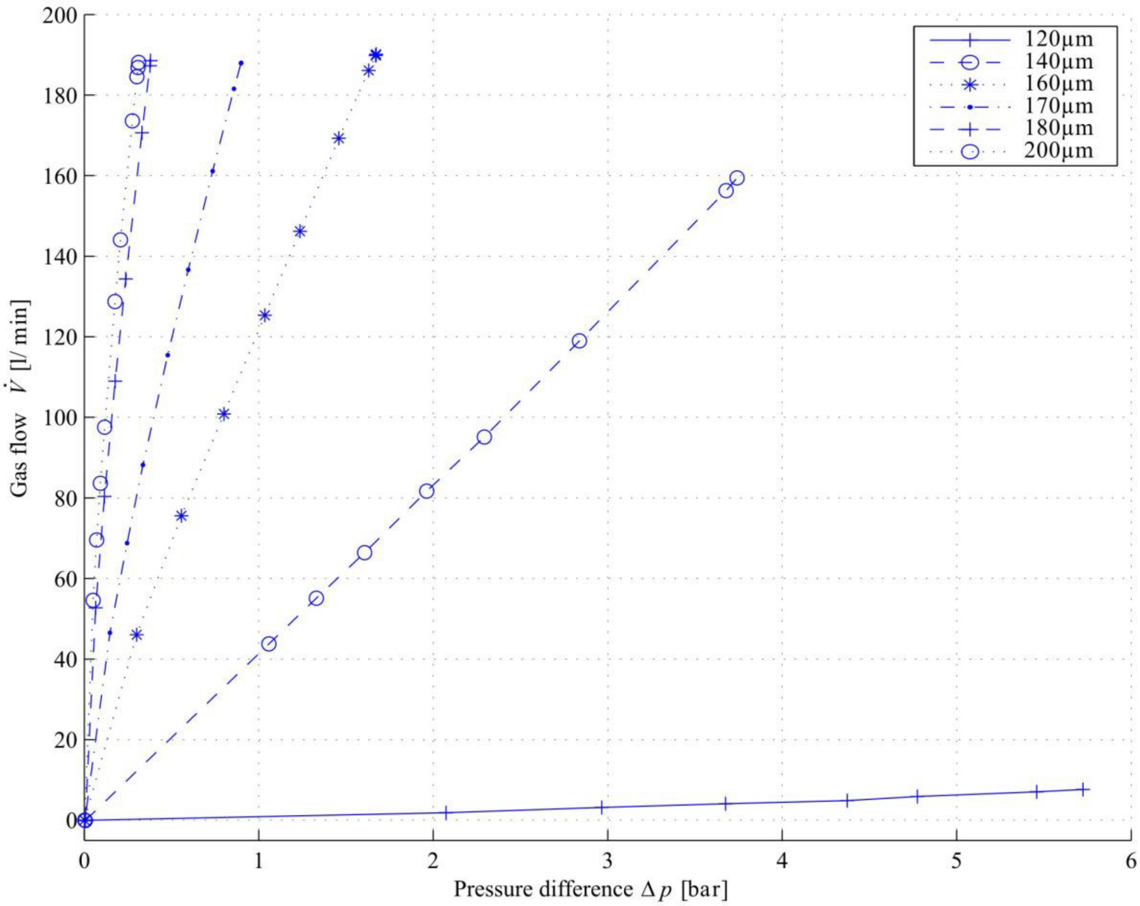

Fig. 7. Gas permeability of test samples with hatch distances 120µm to 200µm

For the production of mold inserts with a pneumatic ejector system a hatch distance of 170µm was chosen. The gap geometry was reckoned to provide a sufficient air flow after machining.

4. Field test in the injection molding process

An injection mold was produced to confirm the functionality and reliability of the pneumatic ejector system on an injection molding machine. The part was a small dish with the ejector surface at the bottom. The trials were performed with Polypropylene (PP) and a blend of Acrylonitrile butadiene styrene (ABS) and Polycarbonate (PC). The mold was manufactured in a conventional way and two interchangeable inserts with the pneumatic ejector system were made by laser additive manufacturing. It was seen that the gas flow through the inserts was reduced due to the machining of the mold insert. It was still sufficient to eject the parts. With the inserts two different scan vector lengths were tested. The insert with 10mm long scan vectors failed due to the entering of melt into the air supply channels during the injection phase. This happened during the first shots and showed the limit of the scan vector length. The other insert had 5mm scan vectors. About 60 parts of each of the two different plastics were made and ejected with this insert. This proofs the concept of the pneumatic ejector system. The reliability of the system was shown as well. In the trial with Polypropylene 90% of the parts were successfully ejected. All parts made of ABS+PC were successfully removed from the mold by the ejector system.

After the trials the mold inserts were inspected. The insert with 10mm scan vectors failed due to the lateral force of the injected melt on the walls of the material as described in Section 2. The visual inspection of the second insert showed no traces of plastic within the gaps. Inspection of the surface of the plastic parts revealed a light structuring of the surface, but no defects that would be considered a quality issue. This is a big advantage compared to mechanical ejectors. Those require tight dimensional tolerances in order to leave no marks on the surface of the plastic part. Manufacturing and adjusting such a mechanical system requires skilled labor and a time. The advantage of the pneumatic system is the integration into an insert with a continuous surface. Machining this surface to give it a smooth look is a lot easier than manufacturing and adjusting a set of mechanical ejectors.

5. Conclusion

Laser additive manufacturing is capable of producing gas permeable material, which has a high permeability to air, but is not permeable to molten plastic. To produce such a material the scan vectors have to be placed in a precise manner to form straight walls with the width of one melt track. The walls are vulnerable to lateral forces applied by the melt during the injection phase. Therefor the length of the walls is limited and they have to be arranged in an order in which the ends of the walls are supported.

Taken these limitations on the structure into account it is possible to design and manufacture a pneumatic ejector system. The system consists of a solid body, an optional cooling system, air supply channels and a layer made of gas permeable laser additive manufactured material. All elements are an integral part of the insert. They are built up together and do not have to be assembled after laser additive manufacturing. The functionality and reliability of the pneumatic ejector system was confirmed during trials on an injection molding machine. Further trials on the long term stability against fatigue and deposition of fumes in the channels will follow.

The pneumatic ejector system offers a large potential to the mold manufacturing industry. It fully replaces the mechanical ejector system. This saves time in mold manufacturing and assembly and therefor costs. The effect on the quality of the parts is neutral compared to a well-adjusted mechanical ejector system. The quality advantage of the pneumatic system is the robustness of the surface finishing process.

Acknowledgements

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References

Feldhaus, A., 1993. „Instandhaltung von Spritzgießwerkzeugen - Analyse des Ausfallverhaltens und Entwicklung angepaßter Maßnahmen zur Steigerung der Anlagenverfügbarkeit“. Verlag der Augustinus Buchhandlung, Aachen

Gesamtverband Kunststoffverarbeitende Industrie e.V., 2011. „Produktionsmenge und Umsatz der Kunststoff verarbeitenden Industrie nach Branchen 2009/2010“.

Menges, G., Michaeli, W., Mohren, P., 2007. „Spritzgießwerkzeuge - Auslegung, Bau, Anwendung”. Hanser, München.

Over, C., 2003. „Generative Fertigung von Bauteilen aus Werkzeugstahl X38CrMoV5-1 und Titan TiAl6V4 mit Selective Laser Melting“. RWTH Aachen, Shaker, Aachen.

Stoffregen, H., Fischer, J., Siedelhofer, C., Abele, E., 2011. „Selective Laser Melting of porous Structures“, Proceedings of the 22nd Annual International Solid Freeform Fabrication (SFF) Symposium, University of Texas, Austin, p. 680

Trenke, D., 2006. “Selektives Lasersintern von porösen Entlüftungsstrukturen am Beispiel des Formenbaus”. TU Clausthal, Papierflieger, Clausthal-Zellerfeld.

Vogel, H., Tangwiriyasakul, C., Emmelmann, C., 2007. “Analysis of Cooling Channel Design for Injection Molds Manufactured by Laser Freeform Fabrication”, Proceedings of the Fourth International WLT-Conference on Lasers in Manufacturing 2007, AT-Fachverlag, München.

Yadroitsev, I., Gusarov, A. V., Yadroitseva, I., Smurov, I., 2010 (a). “Single track formation in selective laser melting of metal powders” Journal of Materials Processing Technology, 210, Elsevier, p. 1624.

Yadroitsev, I., Smurov, I., 2010 (b). “Selective laser melting technology: from single laser melted track stability to 3D parts of complex shape”, Laser Assisted Net Shape Engineering 6, Proceedings of the LANE 2010, Elsevier, p. 551.

Yasa, E., Kempen, K., Kruth, J.-P., Thijs, L., Van Humbeeck, J., 2010. “Microstructure and mechanical properties of Maraging Steel 300 after selective laser melting”, Proceedings of the 21st Annual International Solid Freeform Fabrication (SFF) Symposium, University of Texas, Austin, p. 383.