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ADDITIVE MANUFACTURING OF PARTS WITH INTEGRATED FUNCTIONS

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Abstract: *Due to the lack of tools, additive manufacturing harbours considerably on increased design freedom for the direct integration of functions in comparison to conventional production techniques. Design layout for elements with functions like snap-fits or film hinges, as described in literature for injection moulding, doesn't exist so far. In order to correct these deficiency, studies for the manufacturing of functional parts were done to achieve design layouts suitable for Rapid Manufacturing. Aim was the firsttime establishment of concrete design guidelines for additive manufacturing.*
Key words: *additive manufacturing, design guidelines, laser sintering, integration of functions*

1. INTRODUCTION

Additive manufacturing offers an option to manufacture products with high complexity, undercuts and integrated functions without using intrinsic tools. However, Rapid Manufacturing is only used in a small amount of applications like the manufacturing of dental caps, jewellery or hearing devices (Gebhardt, 2007). Therefore, the main reasons are the lack of generally accepted design guidelines for the dimensioning and the design of parts, as they exist for conventional techniques like die casting, forming or injection moulding. Nevertheless some approaches do exist to use the potentials of additive manufacturing for the production of functional parts (Gebhardt, 2007). Possibilities for integration of functions are parts with textured surfaces (Kruf et al., 2006) or snap-fits (Luscher, 2001). Watts researches the chance of weight reduction in additive manufacturing by topology optimization in Watts & Hague in 2006. First steps for a design suitable for Rapid Manufacturing are described by Becker in (Becker et al., 2005) and Kruf in (Becker et al., 2005). However, up until this time there has yet to be general guidelines with exact rules and standardised function elements.

2. MOTIVATION

Aim of the researches done was the first time establishment of generally accepted design guidelines for Rapid Manufacturing. Up until now, parts have been designed for conventional production techniques and only build with additive manufacturing techniques. With the newly established guidelines the design of parts for RM has become possible for the first time. Geometrical limitations were established in a first step. Based on these results various functions (Piano hinges, film hinges, springs and snap-fits) and rules for conventional manufacturing techniques were verified for laser sintering.

geometry	limitations in [mm]	
	x-/y-direction	z-direction
Wall thickness	≥ 0.5	≥ 0.5
clearance	≥ 0.7	≥ 0.7
cylinder	≥ 1.0	≥ 1.2
hole	≥ 1.2	≥ 1.4

Tab. 1. Established geometrical limitations

3. EXPERIMENTS AND RESULTS

3.1 Geometrical Limitations

Geometrical limitations in laser sintering depend heavily on the used set of parameters and the quality of the laser used in the machine. Due to this fact producers and users who work with laser sintering were interviewed to achieve first values for the geometrical limitations. Afterwards, these limitations were researched systematically with the help of different specimen to validate and compliment the newly established rules. The established design guidelines are shown in Tab.1. The results show that laser sintering is suitable to fabricate fine structures.

3.2 Piano Hinges

Piano hinges are a very common and wide spread connection element for several applications. Laser sintering offers the possibility to integrate these hinges direct in the parts without the need of joining them afterwards.

Based on the found clearances, the minimal fabricable gaps in radial and axial direction were researched to enable the manufacturing of piano hinges. To achieve this purpose the clearances were varied for different densities of energy. In this context it became obvious that by mutual movements of the connected elements even smaller gaps than the found clearances could be freed from powder. However, there have to be holes ≥1.5 mm along the hinges in order to clean the gap of the powder. Other influences can be found in the orientation of the parts and the used density of energy. A high density of energy leads to more caking of the powder in the gap, whereby the removal of the powder is hindered. The researches showed that piano hinges can be fabricated with an axial clearance of minimal 0.2 mm and a radial clearance of minimal 0.4 mm. If lower densities of energy are used smaller clearances are possible.

3.3 Film Hinges

Film hinges are a common used element to connect two parts in injection moulding. Laser sintering gives the potential to manufacture film hinges directly. A detailed description of the design layout of film hinges for injection moulding can be found in (Erhard, 2008). In IM the strain limit ε_G is used to dimension the film hinge. This one is determined as a part specific value directly on film hinges to regard the higher stress and strain values at stretched cross-sections (Erhard, 2008). These can not be detected in a standardised tensile test. The permitted strain in the film hinge is then risen out of the strain limit using a safety factor S.

In contrast to that point, laser sintered parts show considerably lower elongation at break than injection moulded parts (PA 2200: 20 % in x-/y-direction). Therefore, only minor stretching and changes of the cross-section occur. In that case, the technical stress-strain behaviour is nearly identical to the real one. Because of this the elongation of break ε_B was used to dimension the film hinges for laser sintering. The required length L is calculated by equation 1 as a function of the thickness h and the bending angle β (Kunz et al., 2007):

film hinge thickness in [mm]	required safety factors
0.3	≥1.0
0.4	≥1.0
0.5	≥1.0
0.6	≥1.2
0.7	≥1.33
0.8	≥1.75

Tab. 2. Required safety factors for 100 turns

$$L = \frac{h \cdot \beta \cdot S}{2 \cdot \varepsilon_B} \quad (1)$$

The examination of the rules was made for 100 turns with safety factors of 1.0 to 2.0 and a bending angle of 180°. The orientation of the film hinge in the x-/y-plain was found as the optimal part orientation. The necessary safety factors can be found in Tab. 2. It could be verified that a design layout of film hinges is possible using the rules available for injection moulding based on the elongation at break.

3.4 Springs

The direct integration of springs in parts gives many new possibilities for various applications. In injection moulding the fabrication of springs always depends on the demoulding of the part, whereas laser sintering, thanks to design freedom, offers the possibility to manufacture integrated springs in standard forms and even in special forms. During the research, the properties of laser sintered pressure springs were characterised. In this context the interrelationship between the spring constant R (equation 2) and the different spring dimensions (wire diameter d, spring diameter D, spring length L and lead s) were researched (Muhs et al., 2003).

$$R = \frac{G}{8} \cdot \frac{d^4}{D^3 \cdot n} \text{ with } n = \frac{L}{s} \quad (2)$$

The analysis was done for springs in different sizes and orientations. Each laser sintered spring showed off a nearly linear spring characteristic. Fig. 1 shows for example the interrelationship between the wire diameter and the spring constant. An influence from the part orientation to the spring characteristic could not be detected. The researches showed that the interrelationship described in equation 2 can be obtained in most parts for laser sintered springs, too.

3.5 Snap-fits

Snap-fits are a current connection element for laser sintering. However, adequate rules for the design layout are still missing. The maximum load on the snap-fit is due to the joining of the connection. Here the permitted strain ε of the material must not be exceeded. As a reference value for injection moulding about 70 % of the elongation at yield is valid for materials with a distinctive yield point (Ehrenstein, 2002). To verify these rules, laser sintered snap-fits with rectangular cross-sections and ring segments were tested.

To research the function and the maximum outer fibre strain ε laser sintered snap-fits with different dimensions were built. These result from equation 3 for rectangular cross sections respectively ring-sections with the snap-fit length L, the undercut f, the thickness h and the outer diameter ρ_2 (Ehrenstein, 2002).

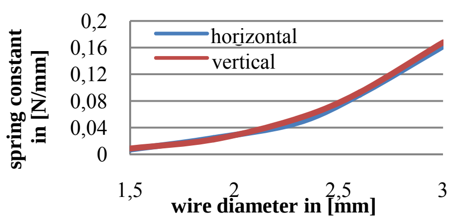

Fig. 1. Spring constant in dependency of the wire diameter

$$f = 0.67 \cdot \frac{\varepsilon \cdot L^2}{h} \text{ or } f = C \cdot \frac{\varepsilon \cdot L^2}{\rho_2} \quad (3)$$

The elongation at yield of the used PA 2200 was found by 11%. The permitted strain is then 7.7%. During the tests the length, thickness and undercut of the snap-fits were varied. The analysis showed that to achieve functional connections an undercut of minimum 1.5 mm for a rectangular cross section respectively 1.0 mm for a ring-segment is necessary. Within the limits of the maximal permitted strain functional snap-fits result regularly from L:h ratios of 6:1 to 3.5:1 for rectangular cross-sections and 6:1 to 4.5:1 for ring-segments. As the result the applicability of the rules for injection moulding could be proved right for laser sintering.

4. CONCLUSION

Within the analysis some first rules for the manufacturing of parts with integrated functions could be established and validated for laser sintering. These rules enable engineers for the first time ever to fully utilize the potentials of additive manufacturing and dimension products suitable for Rapid Manufacturing. Additionally, defective parts can be avoided thanks to the determined geometrical limitations. The research contemplated only the laser sintering as additive manufacturing technique and some function elements. In the future, more elements shall be analysed and the rules should also be verified for other additive manufacturing techniques. Corresponding research projects are planned for the coming years.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Becker, R.; Grzesiak, A.; Henning, A. (2005). Rethink assembly design. *Assembly Automation*, Vol. 25, No. 4, P. 262 - 266, ISSN 0144-5154

Ehrenstein, G.W. (2002). *Mit Kunststoffen konstruieren*, Carl Hanser Verlag, ISBN 3-446-41322-7, München - Wien

Erhard, G. (2008). *Konstruieren mit Kunststoffen*, Carl Hanser Verlag, ISBN 3-446-41322-7, München

Gebhardt, A. (2007). *Generative Fertigungsverfahren - Rapid Prototyping - Rapid Tooling - Rapid Manufacturing*, Carl Hanser Verlag, ISBN 3-446-22666-4, München

Kruf, W.; van de Vorst, B.; Maalderink, H.; Kamperman, N. (2006). Design for rapid manufacturing functional SLS parts, *Proceedings of the 2nd IPROMS Vitual International Conference on Intelligent Production Machines and Systems* , Pham, D. T. (Ed.), P. 389 - 394, ISBN 0-0804-5157-8, Cardiff, July 2006, Elsevier, Kidlington - Amsterdam

Kunz, J.; Bachmann, S.; Studer, M. (2007). Filmgelenke dehnungsbezogen ausgelegt. *Kunststoffe*, Vol. 12/2007, S. 129 - 132

Luscher, A.F. (2001). Use of selective laser sintering for the function testing of snap-fits, *Proceedings of the Antec Conference 2001*, P. 2491 - 2493, ISBN 1-5871-6098-6, Dallas Texas, May 2001, CRC Press, Boca Raton Florida

Muhs, D.; Wittel, H.; Becker, M.; Jannasch, D.; Voßiek (2003). *Roloff/Matek Maschinenelemente*, Vieweg Verlag, ISBN 3-5280-7028-5, Wiesbaden

Watts, D.M.; Hague, R.J. (2006) Expoiting the design freeform of RM, *Proceedings of Solid freeform fabrication symposium 2006*, Bourell, D. L. (Ed.), P. 656 - 667, Austin, Texas, August 2006, University of Texas, Austin Texas