Elastomers of the Third Dimension

Silicones as a Material Group for Additive Manufacturing on the Test Bench

In addition to improved plant technology, new materials are being developed for additive manufacturing processes. These include elastomers which, by their irreversible cross-linking, have a different behavior than thermoplastics. An investigation shows that commercially available silicone rubbers can be processed via additive manufacturing – with high strength in relation to conventionally manufactured silicone rubbers.

In tensile test, the additively manufactured test specimen made of silicone rubber shows a strength which corresponds to approximately 70 % of conventionally produced elastomers (© IKV)

The Institute of Plastics Processing (IKV) at RWTH Aachen University examined the processing of silicone rubber in an additive manufacturing process. For this purpose an available Fused Deposition Modelling (FDM) manufacturing cell was extended for the processing of silicone rubbers. In the conventional production of silicone components, the rubber is processed cold and heated after shaping. The vulcanization starts as a result of heating, the rubber-specific highly elastic bonds are formed, and the rubber is cross-linked. During the heating in the mold, the viscosity of the rubber decreases first before the starting cross-linking causes an increasing viscosity. **Figure 1** shows schematically the change in viscosity. In the case of additive manufacturing, this viscosity change due to the heating is a considerable disadvantage, since here the component is shaped without tools and thus the contour is not fixed and difficult to maintain.

UV-Curing LSR for Additive Manufacturing

This problem is handled by using a high-viscosity UV-curing liquid silicone rubber (LSR, type: Silopren UV LSR 2060, manufacturer: Momentive Performance Materials Inc., Waterford, NY/USA). The gel-like nature of this material is excellently suited for continuous processing using FDM. During the deposition process, a UV radiation source donates the required cross-linking energy. Since the rubber is not heated in this case, the viscosity does not decrease. The created contours maintain their shape during the cross-linking process, even without tools. By varying the input radiation energy over pulse duration and radiation intensity, the degree of cross-linking in the deposed material line can be adjusted. The cross-linking should produce a sufficient dimensional stability which can bear the weight force of the

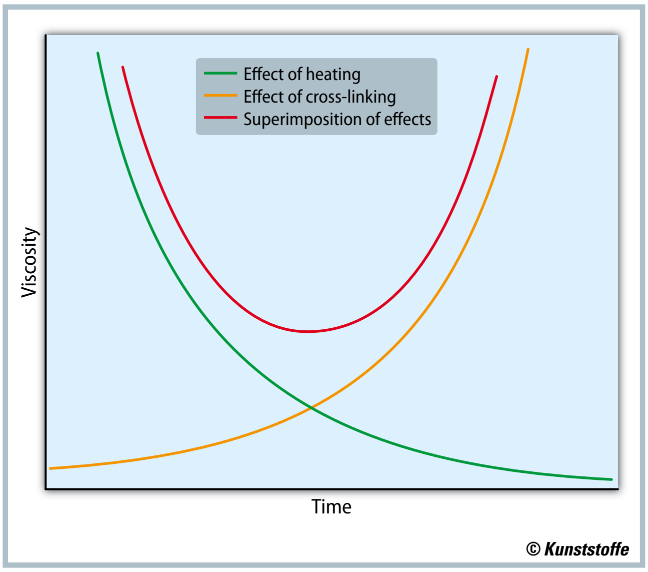

Fig. 1. Superimposition of the effects of heating and cross-linking on the viscosity of rubbers. In printing applications, a low viscosity is disadvantageous, since the contour is not sufficiently dimensionally stable (source: IKV)

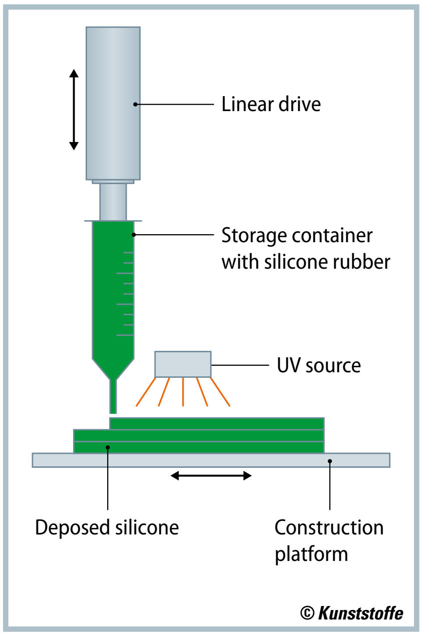

Fig. 2. Principle of the printing process: Silicone is extruded from the storage container and deposed in lines on a construction platform. A UV source donates the required cross-linking energy (source: IKV)

overlying line without deformation. In addition, it must run so slow that the cross-linking is not finished when the overlying line is deposed. This ensures chemical connections between the individual material lines. This cross-linking ensures both sufficient accuracy as well as high mechanical properties of the component. Thus, components with high strengths and elongation rates can be produced, similar to serial production by molding tools. This is a special feature in comparison to additively manufactured components made of thermoplastics since these usually have a series of weld lines which have a negative effect on the strength.

The prototype of an additive manufacturing line for LSR developed at IKV Aachen is based on the K8200 kit from Vellemann N.V., Gavere, Belgium. The silicone rubber is conveyed from the storage container onto the building platform by a linear drive (**Fig. 2**). The desired contour is created by the movements of the construction platform. During deposition, a UV source (type: Bluepoint 4, manufacturer: Dr. Hönle AG, Gräfelfing, Germany) donates the required energy for the cross-linking. After completion of the entire print, additional UV radiation is applied to cure the entire contour.

Comparable Mechanical Properties

S2 tensile bars according to DIN 53504 were manufactured as test specimens in order to compare these with conventional elastomer specimens produced by the pressing process. Both samples were tested in a tensile test. The tensile strength and elongation of the additive manufactured specimen were only a third less than that of conventionally prepared samples (**Fig. 3**). Compared to the additive manufacturing of thermoplastic components which only achieve 40–60 % of the tensile strength of their injection-molded counterpart [1], this value is remarkable. Nevertheless, the additively manufactured silicone parts show air inclusions, which are created during processing and weaken the component. If this can be prevented by suitable adjustment of the process, a further increase in the strength of the additive-finished component is to be assumed.

The variation of the induced radiation energy during 3D printing shows the potential to further increase the strength: a lower pulse distance increases the radiation energy input. The UV radiation increases the viscosity of the silicone so that when the material lines are laid down, gabs can be filled out only poorly and thus more air inclusions are generated. The resultant imperfections weaken the component additionally, whereby the maximum achievable tensile stress is reduced. When the stress-strain curves in **Figure 4** are compared, the curves are congruent. They differ only in the breaking point, which occurs earlier in the additive manufactured samples. Due to the accordance, it can be assumed that the internal properties and bonds are comparable to conventionally prepared samples. »

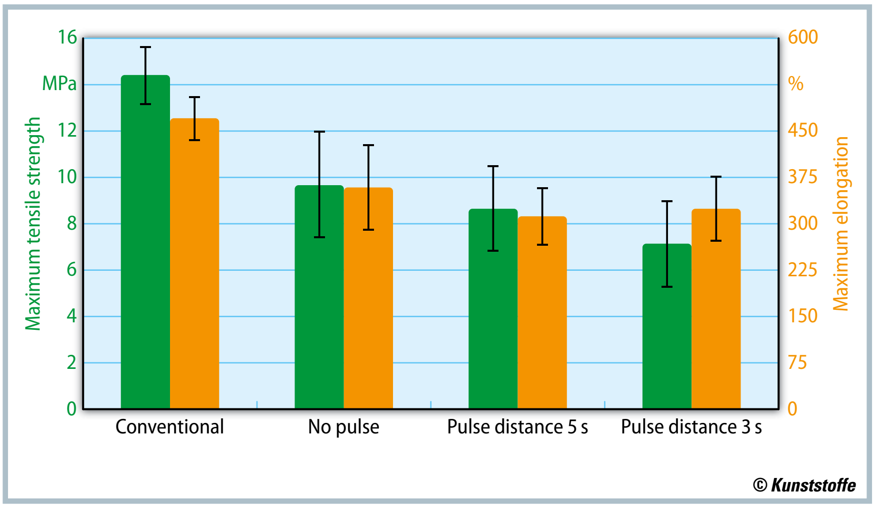

Fig. 3. Comparison of the maximum tensile stress and elongation of conventional and additive manufactured specimen under variation of pulse distance (source: IKV)

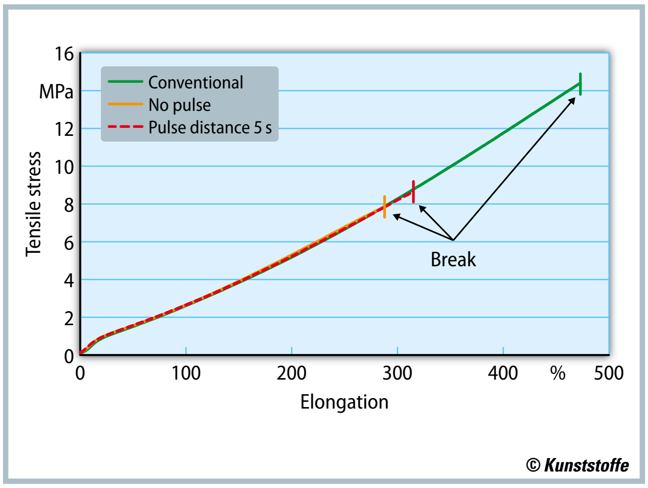

Fig. 4. Tensile stress-strain curves of conventional and additive manufactured specimens (source: IKV)

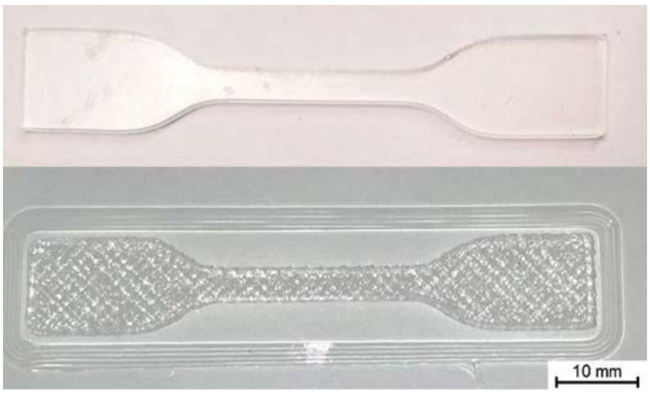

Fig. 5. Comparison of the surface quality of the conventional (top) and additive manufactured (bottom) specimens (© IKV)

Surface Quality Shows Potential for Improvement

The observation of the additive manufactured samples show a poorer surface quality compared to pressed samples (**Fig. 5**). Due to the continuous deposit at an angle of ±45°, "mountains and valleys" and a large number of air inclusions are created. These scatter the incident light strongly, whereby the additive parts are opaque. While the underside of the specimens is planar by contact with the building platform, numerous grooves are visible on the upper side. In general it has been observed that a lower crosslinking radiation during the line deposit results in better surface qualities. A levelling connected to the layer deposit could also allow a better surface.

Conclusion

The IKV Aachen prototype system demonstrates that additive manufactured elastomer components made from standard silicone rubbers are possible. It is remarkable that elastomer components produced by the additive manufacturing process already reach 70 % of the strength of conventionally produced elastomers, despite the uneven surface. In comparison to these, additive manufactured thermoplastic parts achieve only 40–60 % of the strength of their conventional produced counterparts. The molecular bonds of the additive manufactured LSR have similar qualities as the components of the conventional method. At the same time, there is a significant potential for improvement in the process management, so that better component qualities can be achieved with simple measures such as, for example, the adaptation of the radiation intensity or the traversing speed and a levelling. ■

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References & Digital Version

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