3D Printing with Pellet Extruded Plastics on Metal

Plastic-Metal Hybrid Cuts Costs and Time in Additive Manufacturing

Additive manufacturing processes count as future-oriented manufacturing techniques. Numerous studies and award-winning demonstrators underline the interest of the industry. Nevertheless, up to now there are only a few plastic-based applications with significant quantities. Today, screw-based additive manufacturing is a solution for the economic and technical challenges and has the potential for series production.

The bicycle frame (600 g, produced in 80 min) is printed directly onto a metal sheet. This combination unites the advantages of two worlds

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The debate surrounding the conditions for cost-effective and scalable additive manufacturing processes is currently dominated by a certain amount of wishful thinking. In many cases, the feasibility of a specific realization can be called into question as from the very beginning of the project due to the lack of an economic basis and the high requirements on the mechanical properties of the components. Certainly, additive manufacturing offers advantages in terms of tool maintenance, flexibility, freedom of design and functional integration. However, the simple fact remains that the transfer to mass production is never carried out if the resulting production costs per part exceed the current possibilities of a mold-based process. We also need to break free from the mindset of manufacturing current injection molding designs with a 3D printer. Like any production process, additive manufacturing processes require specific designs to reach their full potential.

In this situation, a team of scientists at the Institute for Plastics Processing (IKV) at RWTH Aachen University, Germany, developed a screw- and robot-based additive manufacturing process and introduced it for the first time during the Plastics Technology Colloquium 2016 in Aachen [1]. This concept was applied by Yizumi Germany GmbH, Alsdorf, Germany, involving the same research team, and was industrialized into a scalable production system.

The technical key element is a lightweight extruder weighing only 7.5 kg. It can still be used to process all common materials from PMMA and PC to PP and PA – with and without fiber reinforcement. At the same time, the lightweight construction approach also allows for small robot sizes to be used. Their range is usually more than sufficient.

Using Strand Shapes to Systematically Influence Anisotropy

Considering the required mechanical properties, the use of fiber-reinforced plastics is particularly beneficial for structural 3D-printed components. The use of pellets enables a higher content of reinforcing materials compared to other additive manufacturing processes. All manufacturing processes influence the fiber orientation and therefore the mechanics of a plastic part. Due to the excellent mechanical and rheological properties as well as the high thermal conductivity, which contributes to the dissipation of heat during layer composition, carbon fiber-reinforced materials are highly suitable for a fast additive manufacturing process. A carbon fiber-reinforced polyamide 6 (grade: Akromid B3 ICF 30 9 AM black (7451); manufacturer: Akro-Plastic GmbH, Niederzissen, Germany) is used in the following investigations.

By adapting the processing, the anisotropy of the mechanical properties can be significantly influenced. An anisotropic behavior is influenced by the parameters of the selected nozzle diameter as well as the ratio of feed rate and mass flow relative to the nozzle diameter.

Three different types of strand shaping can be defined. This means that we are dealing with either a preceding melt, a drawn melt or an intermediate state. Based on these boundary conditions, the fiber and molecule orientation of a drawn melt is stronger than that of an preceding melt.

Examining the flexural modulus and flexural strength, a significant increase in the mechanical properties can be seen with increased nozzle diameter at identical strand width (**Fig. 1**). Due to the increased anisotropy, the 3D-printed test specimens reach the property range of injection molded parts.

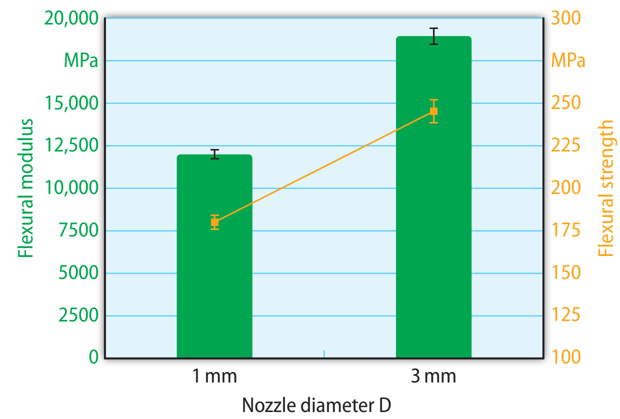

Fig. 1. Increasing nozzle diameters have a positive effect on the anisotropy of mechanical properties in the part Source: Akro-Plastic/Yizumi; graphic: © Hanser

Why Does 3D Printing Plastics Need Metal?

The integration of metal components in 3D-printing is advantageous for several reasons. Firstly, hybrid structures offer the opportunity to use materials according to requirements. Secondly, flat structures, which can only be printed inadequately by hatching operations, can be easily integrated. The flat, aerial pattern is simply added to the process as a semi-finished product.

This also replaces the necessary building platform management. The "building platform" remains in the part as a functional component. Thirdly, both aspects save time and money. Apart from additive manufacturing on metal sheets, the hybrid process also opens up the option of direct manufacturing on three-dimensional structures (metallic or polymer).

Automated Production of Hybrid Parts

In a first step the required metal sheets are coated with a storage-stable plasma-polymerized adhesion modifying layer using the PST process (Plasma-SealTight) developed by Plasmatreat GmbH, Steinhagen, Germany, and Akro-Plastic GmbH. The process is successfully used in injection molding to produce high-strength plastic-metal bonds [2, 3]. The metal sheet can then be printed on directly after the coating.

At this point, it is important to ensure a sufficient contact temperature between the sheet metal and the melt. A variothermal fixture is required for this. In contrast to variothermal injection molding, it can be very compact and feature heating elements close to the surface, since the forces on the mold are much lower than in injection molding.

The processes can be combined with different metals [2]. In an initial process evaluation, an aluminum alloy and stainless steel were used to produce beam structures and the test specimens used in the following investigations [4]. However, to evaluate the mechanical potential of the plastic-metal hybrid bond, it is necessary to investigate the influencing parameters.

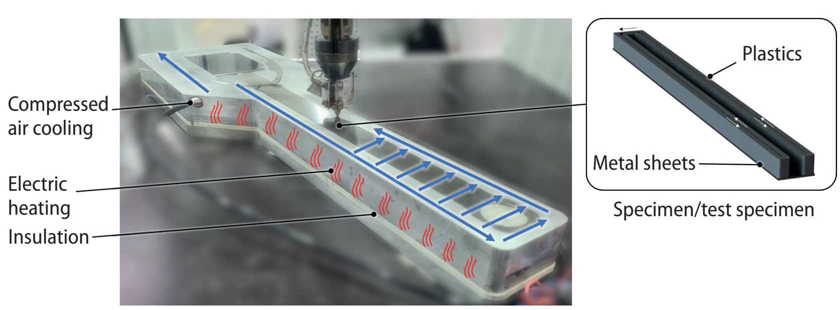

Fig. 2. Test set-up: variothermal fixture in production area of a SpaceA manufacturing unit, temperature load cycle and test specimen geometry © Yizumi

Approach to Analyze the Mechanical Properties

In order to investigate the influences of the combination of processes and materials on the mechanical properties of 3D-printed plastic-metal hybrids, test specimens for three-point bending tests were developed in accordance to DIN EN ISO 178. The plastic component of the test specimens consists of a closed contour of four parallel strands over the entire test area. The height of the test specimen is set at 10 mm. »

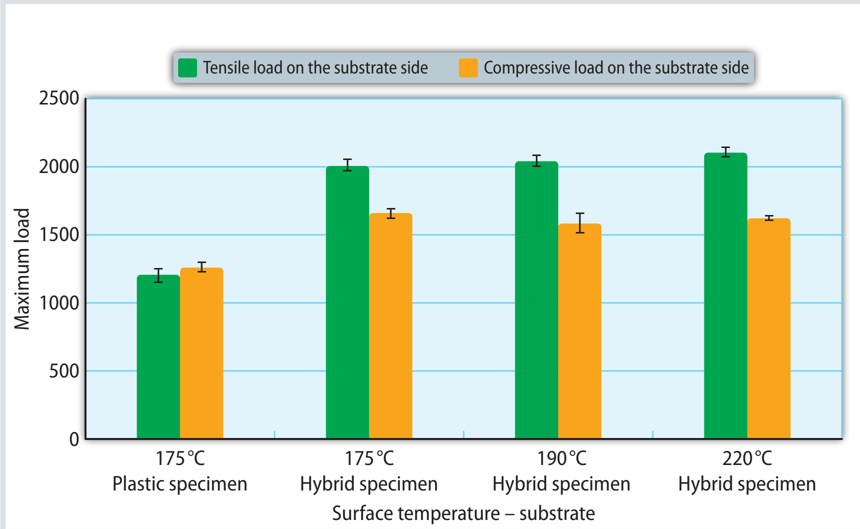

Fig. 3. Maximum load at different insert temperatures. This demonstrates the strong bond between plastic and metal over a wide temperature range Source: Akro-Plastic/Yizumi; graphic: © Hanser

To reduce the influence of shear stress on the layered test specimens, the length to height ratio was defined to 25 [5]. Plastic test specimens and hybrid test specimens fitted with 1 mm thick stainless steel inserts were used in testing (**Fig. 2**).

To assess the process influences of 3D-printing, the nozzle diameter is varied at constant strand width during the production of the plastic specimen. As part of the experimental design, the peak temperature of the variothermal fixture is also varied. The surface temperature of the metallic insert was set to 175 °C, 190 °C and 220 °C. During the production of the plastic test specimens, the variothermal heating with a peak temperature of 175 °C is maintained on the surface of the fixture.

The plastic and hybrid test specimens are tested in a three-point bending with a span of 200 mm and scaled test speed. The force is applied both on the substrate side and on the side facing away from the substrate, so that the metal inserts are loaded in tension or compression.

Mechanical Properties at an Optimal Level

The temperature influences of the metal insert on the mechanical properties of plastic-metal hybrids are shown in the results (**Fig. 3**) and exemplary force/displacement curves (**Fig. 4**). The data shows a high consistency with minimal scattering of the maximum force. Due to the negligibly small stan-

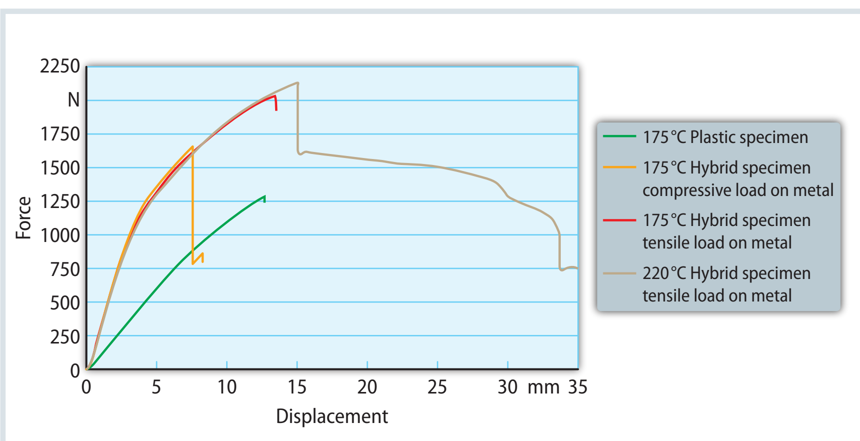

Fig. 4. Force-deformation chart of the tested specimens. The hybrid structure increases the stiffness and strength compared to plastic-only test specimens Source: Akro-Plastic/Yizumi; graphic: © Hanser

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References & Digital Version

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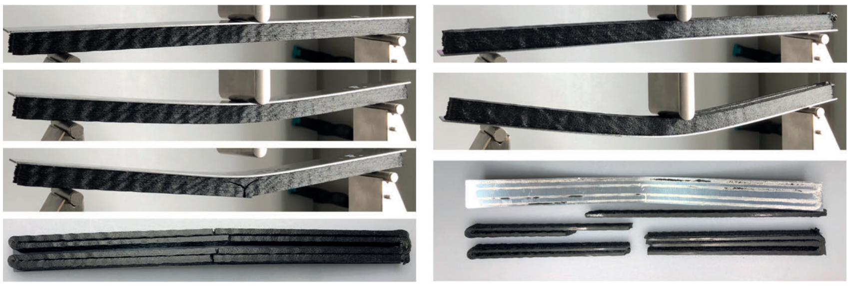

Fig. 5. Testing of the hybrid part: initial position (force applied to the metal component on the left, force applied to the plastic component on the right), maximum deflection of the test specimen and failure with fracture mode (insert temperature 175 °C) © Akro-Plastic/Yizumi

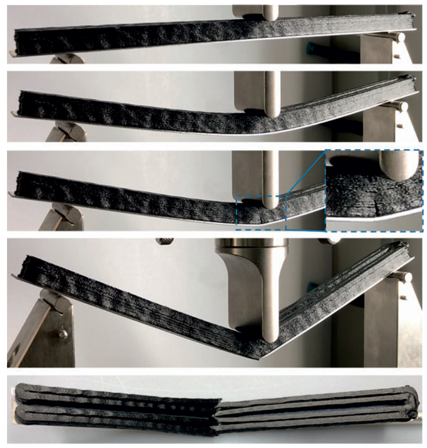

Fig. 6. Test in starting position (force application to the plastic component), maximum deflection of the test specimen and failure with fracture mode (insert temperature 220 °C) © Akro-Plastic/Yizumi

dard deviation the processing is regarded to be robust.

The achieved maximum force, which is almost twice that of a plastic part, illustrates the mechanical potential of 3D-printed plastic-metal hybrids. Moreover, this is also reflected in the increased stiffness of plastic-metal-hybrids (**Fig. 4**). On the other hand, it can be seen that the flexural strength does not increase significantly above an insert temperature of 175 °C, irrespective of the type of load on the metal component. Thus, excellent bonding behavior is achieved over a wide temperature range.

However, the fracture behavior varies considerably throughout the temperature range, as the various temperature and load-dependent strain at break illustrates. At the same temperature (175 °C), when load is applied to the metal component, the plastic component fails in the extreme outer fiber under tensile load resulting in a migrating crack through the plastic at the slightest deflection. The bond between metal and plastic remains intact.

When load is applied to the plastic component at the same temperature, the applied force leads to plastic deformation of the metal component. The failure in turn occurs in the plastic under tension and thus in the interface between metal and plastic. This results in a complete separation of the plastic component (**Fig. 5**). The fracture patterns indicate a well-developed bond between plastic and metal. The residues on the metallic surface after test show that the failure occurs in the plastic component.

With an increased insert temperature of 220 °C, the failure mode changes. It is remarkable here that the deflection nearly triples until the total failure of the test specimen (**Fig. 6**). With regard to stiffness and the progression before reaching the force maximum, the test characteristics of specimens at higher temperatures largely match the lower temperature levels (**Fig. 4**).

The fracture mechanics are also impressive at the macroscopic level. Here, too, plastic deformation of the metal component occurs. The fracture also starts at the interface between plastic and metal. However, the bond remains intact. This means that initial failure does not occur between the layers of the 3D-printed plastic, but perpendicular to the direction of the buildup up to the neutral fiber. Further and complete failure is caused by compressive stresses.

Conclusion

As shown, the process for producing a plastic-metal hybrid component can be easily automated (**Fig. 7**). According to the investigations, the bonding strength between metal and plastic via the plasma-polymerized adhesion layer is very high and the resulting parts exhibit improved mechanical properties compared to solely plastic parts.

In addition, the hybrid approach to additive manufacturing also offers economic advantages in comparison to conventional approaches in injection molding. A reduction in component costs of 10 % for the demonstrator (**Title figure**) shown clearly demonstrates the economic potential of additively manufactured plastic-metal hybrids. ■

Fig. 7. A modular plant strategy allows scaling (here the largest model SpaceA 2000–500-S) and integration of all known automation concepts © Yizumi