

# Implementation of virtual models from sheet metal forming simulation into physical 3D colour models using 3D printing

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**Abstract.** Today the methods of numerical simulation of sheet metal forming offer a great diversity of possibilities for optimization in product development and in process design. However, the results from simulation are only available as virtual models. Because there are any forming tools available during the early stages of product development, physical models that could serve to represent the virtual results are therefore lacking. Physical 3D-models can be created using 3D-printing and serve as an illustration and present a better understanding of the simulation results. In this way, the results from the simulation can be made more “comprehensible” within a development team. This paper presents the possibilities of 3D-colour printing with particular consideration of the requirements regarding the implementation of sheet metal forming simulation. Using concrete examples of sheet metal forming, the manufacturing of 3D colour models will be expounded upon on the basis of simulation results.

## 1. Introduction

The Additive Manufacturing (AM) processes, also called 3D Printing (3DP), have greatly advanced over recent years. A common feature of all of these processes is that the work pieces are manufactured in layers by adding the materials. Another important feature is the direct manufacturing of the components on the basis of 3D data [1]. The bonding processes used range from the fusing of powdery materials through the adhering of powders and foils / transparencies to the polymerisation of liquid photopolymers. In this, a wide palette of various materials ranging from plaster through plastic to metals is implemented [2]. The development of the last years has also demonstrated that the use of the processes ranges from simple prototyping to production of small or medium series. Thus, the number of components built by means of AM has continued to increase over the years [3].

Forming is applied in many areas of AM. The AM processes are thus implemented to produce moulds (Rapid Tooling). On one hand, the direct application of tool data from the CAD is used here in order to drastically reduce the production time of tools without the time-consuming programming of tool paths and the tedious set-up of machine tools [4]. On the other hand, tools with complex internal forms are thereby implemented; these tools are not conventionally manufactured. One example of this is the production of tools with internal cooling passages for the hot forming of high-strength steels [5].

Additionally, AM can also be conducive to the production of sample pieces in presentation models. Because, in particular, forming dies are generally not available for the production physical samples during the development phase of formed components, one is limited to virtual models in this integral phase. Sample parts can be additively produced through AM application; these parts, for example, can serve as the basis for discussion with the development team or the client. Simple test trials can also occur with such physical models. Along with rapid availability, the haptic compilation of the model is an essential advantage because using this physical model generates a significantly better understanding of the forming process compared to observing a simple view of the virtual model on a screen.



## 2. Additive Manufacturing of 3D colour models

With regard to forming, it is especially interesting that not only the geometry but also a colour texture can be displayed with 3D colour printing. This is, in particular, an advantage in the presentation of simulation results. Consequently, complex geometries or the phases of a multistage forming process can be visualised through physical 3D colour prints and haptically “grasped”. Three AM processes can currently be applied for the production of 3D colour models [1]. These differ from one another, particularly, in the layer thickness and accuracy, the joining technologies implemented as well as the necessary post processing and in the construction materials used (see Table 1).

**Table 1.** Additive manufacturing technologies for 3D colour printing.

	Laminated Object Modelling	Binder Jetting	Polyjet Modelling
Construction material	Sheet of paper	Polymer plaster powder	Liquid photopolymer
Layer thickness	approx. 0.1 mm	approx. 0.1 mm	approx. 32 $\mu$ m
Joining technology	Applying adhesive & cutting	Jetting binder	Curing using UV light
Post processing	Removing paper and infiltration	Blowing off powder and infiltration	Removing support structure using water-jet

### 2.1. Laminated Object Modelling

Laminated Object Modelling (LOM) is one of the oldest of a AM processes. In this process, paper is adhered in individual layers. In earlier systems, the paper was unwound from a roll and stuck together in large areas. Then the outline of the component was cut out by means of a laser. In order to reduce the equipment costs, current systems use a cutting blade rather than a laser. The paper is printed in individual sheets in colour and then adhered. Today the adhesive is selectively applied so as to avoid oversaturation and the expansion of the paper. During post-processing, the unnecessary fringe areas and support structure, which was cubed during the previous production process, are first manually removed with the aid of a graver. To increase the stability, the components can be infiltrated with epoxy resin.

### 2.2. Binder Jetting

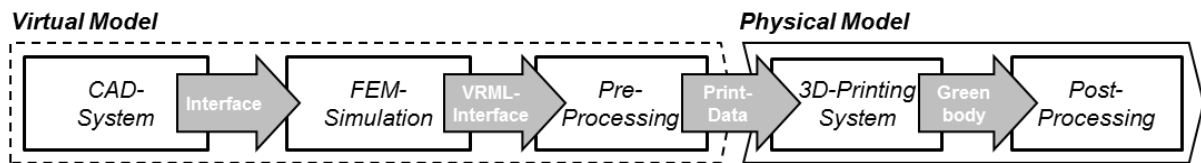
In Binder Jetting (BJ) a polymer plaster powder is adhered by means of a binder. For this, a layer of polymer plaster powder is first applied with a roller. Then a liquid binder is applied with a print head so that the powder adheres. Colours as well as lettering and logos can also be applied with a second print head, similar to that in a conventional inkjet printer. In this, the colouring is only done on one of the approx. 1.5 to 2.0 mm thick edge layers; the core of the component is not coloured. Post processing in this AM process occurs in two steps. First, the 3D printed model is released, and excess powder is cleaned by means of compressed air. Because the 3D printed models, also called “green body,” only exhibit weak stability, they must still be infiltrated with an epoxy resin. This infiltration significantly increases the stability of the model and also improves the brilliance of the printed colours.

### 2.3. Polyjet Modelling

In Polyjet Modelling (PJM), a liquid photopolymer is applied with a print head with a high number of nozzles. The applied layer is cured with UV lamps located directly next to the print head. High precision in detail is achieved through the minimal thickness of the layers. Admittedly, the production times are considerably longer for the same reason. Components that are hanging over are stabilised by support material. Material combinations with diverse features are possible (Digital Materials) through combining several different photopolymers. Moreover, levels of grey or colours as well can be created by these combinations. The support structures must be removed after the actual manufacturing process. Generally, a water jet or an alkaline bath is used for this.

## 3. Process chain from virtual to physical 3D model

During the production of a physical 3D colour model, the data for the virtual CAD model passes through various interfaces and software packages for the simulation and for the data processing (see Figure 1). The production process of the physical model divides itself in applying the component layer by layer and the subsequent necessary post-processing.



**Figure 1:** Process chain from the virtual model to the physical 3D colour model.

### 3.1. Virtual model on the basis of simulation results

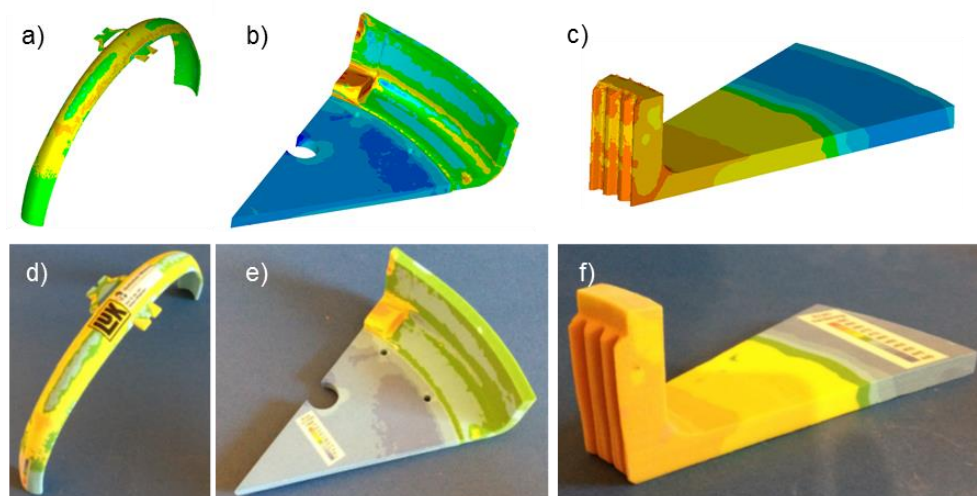
The basis for every AM Process is a 3D model. For conventional applications, this is prepared using a CAD system. Alternatively, 3D scanners can also be used to digitalise existing components or tools. In this process, a time consuming Reverse Engineering is often necessary in addition to the actual scanning in order to transfer the point cloud from the 3D scan to a closed volume model. In contrast to conventional process chain, an additional process step is required in the application of simulation technology. Here the CAD data from the active surfaces of the forming tools is read into the simulation software and then the computation of various parameters takes place. After the completion of the computation, the simulation results are transferred to the data processing. The VRML format is used as the interface between forming simulation and pre-processing, because it can also transfer the texture of the surface. In addition, the positioning and orientation in the installation room of the 3D printer takes place at this point. Then the data read is sliced and transferred as print data to the 3D printer.

### 3.2. Physical 3D colour model

The production of the 3D colour model occurs in a layer by layer application of material. A 3D printer Projet 660 Pro from 3D Systems was used in the examples indicated in Chapter 4 as well. This printer functions according to the BJ process and has an installation room of 254 x 381 x 203 mm (L x W x H). The colour print head can represent 390,000 colours with a resolution of 600 x 540 dpi. A powdery high performance composite material consisting of plaster and polymers is used as construction material. After an idle period of approximately 90 minutes, the excess powder is vacuumed off with a hose in the installation room. Then the component is transferred to a chamber where the remaining powder is blown off with a compressed air pistol. In the second part of post-processing, the component is soaked in epoxy resin or doused with an instant adhesive to improve the stability and the brilliance of the colours.

## 4. Examples of implementing the 3D colour models

The following section presents several examples of the implementation of 3D colour models based on the simulation results in sheet metal forming. The simulation results can thus be read as VRML data and be transferred to the 3D printer. Specific software settings are not required for this. The file can be directly read on the post-processor.



**Figure 2:** Simulation results and 3D colour print of washer (a,d), thick sheet (b,e) and hub (c,f).

A “curved spring washer” is an example of the use of 3D colour printing in sheet metal forming. Various forming stages are optimised and tested with FEM simulation within the framework of a development project. The measurements are 248 x 46 x 113 mm (L x W x H). A particular challenge for sheet metal forming is the minimal wall thickness of the model. Because the 3D model is very fragile when the wall thickness is less than 2 mm, secure handling during post-processing is hardly possible. Therefore, the wall thickness is scaled, i.e. increased, in the course of the data processing (see Figure 2 a, d). Additionally, the colour key and the company logo are applied.

In a second example, the simulation of the forming process of a “thick sheet” with the measurements 150 x 105 x 46 mm (L x W x H) is run as a 3D colour model (see Figure 2 b, e). The round cuttings are generated before the simulation. Because a rotationally symmetrical component is being produced here, only a part model, that is, a cutting of approximately 45°, is simulated and printed. A scaling of the wall thickness of approximately 6.5 mm was not necessary for this model. The colour key is also applied in this example.

A “hub with internal teeth” (see Figure 2 c, f) with the measurements 50 x 26 x 16 mm (L x W x H) is printed as a third example. A segment of 23.5° was also selected from this example. Because this is a very small component, the application of the key is possible but hardly readable. Therefore, an increase of the scale to 2:1 or even 3:1 in the scaling of the data processing is recommended for this example.

Three-dimensional colour printing can also be applied in representing simulation results in massive forming simulation and microstructure simulation [6]. In these applications the 3D-printing of several forming stages and the implementation of “3D-puzzle” could be demonstrated.

## 5. Conclusion

Currently, a variety of Additive Manufacturing Processes that enable the production of 3D colour models are available. Particular attention must be given to the selection of suitable interfaces for data processing in the application of these processes for the production of models based on simulation results taken from forming technology. An optimisation of the component, for example, in thickening the thin and thereby fragile areas, can take place during the data processing. Additionally, a scaling of especially small or large models is possible. Large models have the option to divide the into sections.

The 3D colour models produced in this manner serve the visualisation of complex geometries and detailed simulation results. A simpler “grasping” and better understanding of the geometry and the simulation results is possible with the haptic compilation. Furthermore, an extension of the 3D printing on simulation results from similar areas, such as, e.g., massive forming or even casting, and the representation of microstructure models are possible.

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