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Engineering framework for enabling mass customisation of curvilinear panels with large surfaces by using pin-type tooling

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Abstract

Mass customisation is in contradiction with established manufacturing systems, which produce high quantities of identical parts. Even though products assembled according to individual customer demands are widely available in many areas, the shape of the individual parts of the assembled product is generally fixed. To enable mass customisation regarding the shape of these parts, new manufacturing technologies are needed. Additive manufacturing proved to be an enabling technology for this purpose. For large panels with free-form surfaces and similar parts with curvilinear and large surfaces, however, additive manufacturing is not in such an economical way commonly useful. In addition, panels additive manufactured require a postprocess for smoothing since the staircase effect is related to additive manufacturing. In conclusion, traditional die making is still being used to produce customised panels and the reason why they cannot be produced economically. As addressed in this article, pin-type tooling, however, is a technology that could enable mass customised panels. This paper analyses the challenges of mass customisation and assign them to the characteristics of pin-type tooling. Since new manufacturing technologies and business processes require suitable engineering processes, an engineering framework for producing such mass customised panels with pin-type tooling is introduced.

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1. Introduction

Offering individualised products increases the unique selling proposition and thereby the competitiveness of manufacturers. Ideally, each customer of a mass market gets his or hers individualised product. Mass customisation however is in direct conflict with established manufacturing systems, which are generally designed to produce high quantities of identical parts. Even though products assembled according to individual customer demands are widely available in many areas (e.g. electronics and automotive), the shapes of the individual parts of the assembled product are generally fixed. To enable customisation regarding the shape of these parts and subsequently the design of the product in large scale production new manufacturing technologies are needed which do not raise the cost of production.

2. Additive manufacturing enables mass customisation of panels not entirely

Additive manufacturing represents one suitable technology for producing customised parts in a very small quantity but economical. Was it initially used mainly for rapid prototyping it is meanwhile also applied to produce e.g. direct-to-market products. Compared with tools like moulds for injection or casting, the tool costs within additive manufacturing must not be allocated in a holistic way to a defined geometry respectively one single part, which consequently would lead to high costs per unit if the quantities are small. Different geometries are producible with the same tool and even in the same time on one machine. This allows allocating the tool

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costs to a high number of parts that leads to low tool costs per unit.

However, for large panels with free-form surfaces and similar parts with curvilinear and large surfaces (in the following abbreviated called *panels*) – e.g. windshields or metal sheets in automotive – additive manufacturing is not in such an inexpensive way commonly useful. Since the stair-stepping effect is related to additive manufacturing [1] panels produced in such a way require a post-process for smoothing surface. The stair-stepping effect is reducible by reducing the layer thickness but this results at the same time in an increase in build time [2], since the needed number of layers increases for keeping up the same build height. More layers are needed for filling the same volume. Additionally changes between layers increase, which in turn increases the building time. Moreover, manufacturing based on layers causes anisotropy within the part, which is undesirable in some cases. In summary, additive manufacturing does not enable in an entirely manner producing mass customised panels.

As a result, traditional die making for moulding such panels is characterised by rigid dies. This is still state of the art and the reason why customised panels cannot be produced economically, since the costs of each die are allocated fully to the one belonging panel. As addressed in the following chapter, pin-type tooling is a technology that could well be the key to produce mass customised panels.

3. Pin-type tooling enables mass customisation of panels but requires adequate engineering processes

Pin-type tooling is a die making technology that replaces the commonly used solid die with an array of individually adjustable pins to create a desired freeform shape. This technology was first invented by Cochrane [3] more than 150 years ago and has been improved ever since [4]. Where in the tool created by Cochrane the pins were manually adjusted to produce leaf springs for horse-drawn carriages, later versions of the technology are much more sophisticated. Nakajima [5] designed the first automatically adjustable, computer controlled die consisting of close packed round pins that were adjusted with a positioning stylus fitted to a NC milling machine. In a research project in the 1990s Hardt et al built a *Reconfigurable Tooling for Flexible Fabrication* for stretch forming sheet metal parts [6]. Variations of the technology, all focused on stretch forming and pressing sheet metal, are also known as *Multipoint Forming* [7], *Reconfigurable Multipoint Forming* [8,9] or *Digitized Die Forming* [10].

In all these tools the surface created by the pins is not directly viable as a mould since the shape generated is just a discrete or stepped representation of the desired surface. To create a smooth surface on top of the pins an elastic sheet, called interpolation layer, is introduced to interpolate the surface between the pins as shown in Fig. 1. The applications for these flexible tools have been shown in various areas like in aviation, where aircraft outer skin panels are stretch formed [11], in medicine, where individually fitted cranial implants are made from titanium [12] and in automotive industry, where windowpanes are manufactured from polycarbonate and Plexiglas for use in prototypes [13].

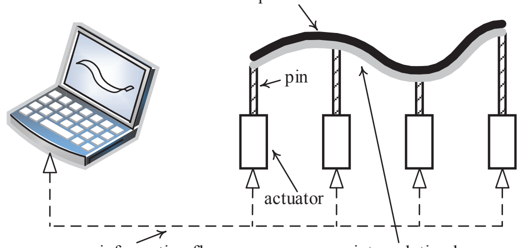

Fig. 1. Schematics of an automated pin-type tool.

The purpose of mass customisation is to better satisfy the customers' needs by increasing variety and customisation of products but at the same time not increasing cost and time effort in producing such products which means being efficient in a way near to mass production [14,15].

Table 1. Comparing demands of mass customisation and pin-type tooling characteristics.

level of mass customization [16]	enabling pin-type tooling characteristic
differentiation based on customised products	Adjusting shape to customers' needs immediately by adjusting pins. Similar to the relationship between additive manufacturing tools and their parts to be produced, the promptly reconfigurable die is independent from the panel to be produced due to actuating immediately the vertical position of the pins. Thus, the engineering and production effort for customised design gets minimised significantly.
cost in a way efficient like in mass production	The deterministic correlation between mould and part gets eliminated. The conventional demand for *each panel needs one belonging die gets lost*. This allows allocating tool costs to a high number of panels resulting in low tool costs per unit. In addition, manufacturing at minimum one rigid die for each panel-geometry is no more necessary. This eliminates following: ▪ material, energy and time consumption for producing rigid dies, ▪ the need for storing and delivering of just unused dies and ▪ expenses for scrapping no longer needed dies. Summarising above enumerations, the waste of resources gets significantly minimised by using pin-type tooling for panel moulding.
relationship to increase customer loyalty	Following both characteristics mentioned above, customer's (geometric) needs are easier to fulfil without additional effort by using pin-type tooling. Thus, the gap between customer's wishes and company's offer gets minimised which is why the relationship gets closer.
solution space	Not the pin type tool itself, but the engineering process needs to enable the solution space, since the product quality depends on the process quality behind it. Thus, engineering processes need to be modified to meet the requirements of mass customisation.

Mass customisation performs on different levels [16]. As shown in Table 1, the characteristics of pin-type tooling hereof fulfil three mentioned levels respectively demands of