The future of fault-proof thermoplastic polymers using overmoulding

Production of complex 3D parts in an automated fashion that ensures quality and strength of the final structure can be tricky, especially for parts produced via overmoulding. During overmoulding, a thermoplastic composite is reshaped with the aid of heat and upon injection of a resin, to obtain a new structure. Prof Remko Akkerman from the Faculty of Engineering Technology of the University of Twente and scientific director of the ThermoPlastic Composite Research Center, studied experimentally and through process simulation the strength at interface of thermoplastic composites derived from semi-crystalline polymers, aiming to create novel design tools.

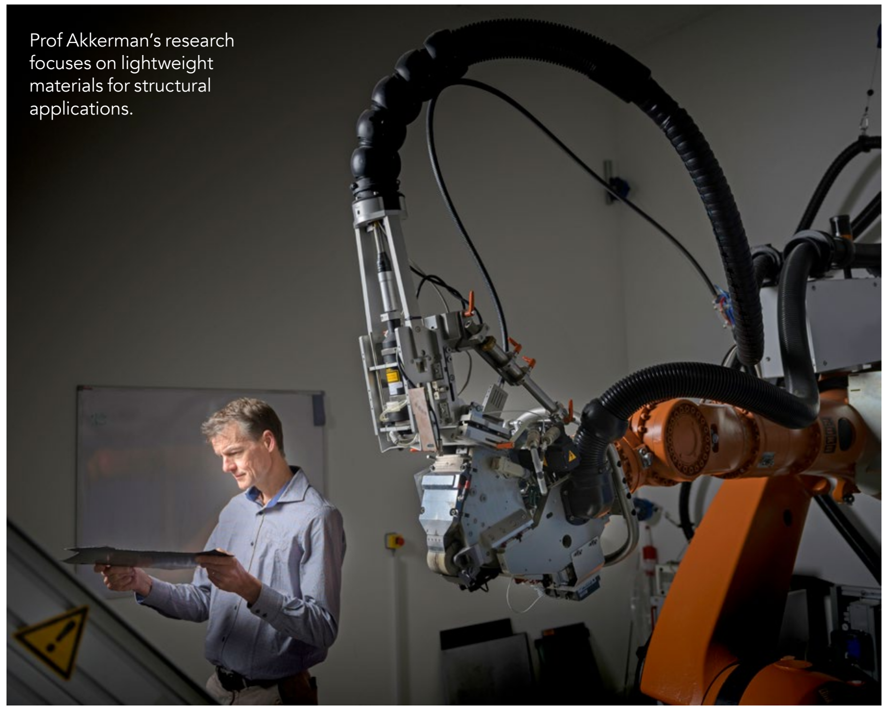
Have you ever seen structures comprised of one or more plastic materials shaped in unconventional, complex three-dimensional (3D) structures? Such structures can usually be found in the back of office chairs or car seats if you remove the padding, or in much more demanding applications, such as in aviation. Structural excellence, integrity, functionality as well as use of lightweight materials are the pillars running through the production of such structures. The choice of plastic materials, also known as polymers, fits the lightweight requirement. However, the formation of complex 3D shapes using potentially different materials for different parts of the structure, in an automated fashion, reducing the possibility of failure upon load, is not an easy task.

THE AMAZING PROPERTIES OF THERMOPLASTIC COMPOSITES

There are two main types of plastics used for the aforementioned structures: injection moulded plastics, usually known as thermoplastics (molten plastic squeezed into place and solidified), and thermosets. Thermoplastic polymers are man-made materials comprised of thousands of monomers, resembling beads of a pearl necklace. If you imagine several strings of pearls intertwined with each other and creating a matrix, this is a good analogy for the representation of a polymer and a polymeric structure. There are hundreds of types of monomers, combinations of the 'strings', and even the possibility to 'mix and match' different monomers and create polymers with new properties. The polymers can be mixed with fibres to make a fibre-reinforced plastic with high stiffness and strength, while retaining low weight.

The main difference between thermoplastics and thermosets is their reaction to heat. In the case of thermosets, once a structure is formed and polymerised, the final product does not allow for re-moulding or melting without breaking down the original chemical structure and properties of the material. This means that once heated above a certain temperature, the material degrades and is rendered unusable.

The initial form of man-made plastics upon production is liquid, and the transition of plastics between non-solid to solid form can occur either due to further reaction between non-solid substances (think of a two-component glue), or upon the presence – or absence – of adequate heating (think of a plate of hot pasta with cheese, mouldable at the beginning, rock solid when cold, mouldable again when heated up). The case of thermoplastic composites falls within the "cheesy pasta" category, where we can heat a solid structure and remould it to create a new one. Therefore, in the case of thermoplastics (and composites with a thermoplastic matrix), we are able to heat the material and re-shape it to a different structure as many times as we like, preserving its strength, visual appearance, and other properties important for its application once re-solidified. Examples of thermoplastics are the commercially famous acrylonitrile butadiene styrene (used in Lego bricks), polyamides (commercially known as Nylon), and polycarbonates (used in motorcycle helmets).



Prof Akkerman's research focuses on lightweight materials for structural applications.

INTRODUCTION TO OVERMOULDING

Now, try to imagine two materials heated and re-shaped together. An example to illustrate that would be two different types of chocolate slabs, slightly warmed, connected together as a "T" or on top of each other, and allowed to cool. The new structure would be a solid structure, comprised of two different types of chocolate, giving the new structure an enhanced set of properties and shape.

Going back to thermoplastic composites, the process of placing a pre-formed piece of material into a mould, injecting a polymer resin, and merging the two materials together into a new shape using heat and pressure is called overmoulding.

The process of the two materials merging into each other, removing any signs of a clearly distinguishable interface between them is called healing, and takes place before the new structure is cooled down and solidified. Correct healing – not being able to distinguish one from the other at the area of contact – requires adequate heat and pressure, and enough time to allow for the merge. However, cycle time (overmoulding, healing, cooling) should be as short as possible to allow for good productivity and return of investment from the usually very expensive mould construction. It should be mentioned that if the two materials used during overmoulding belong to the same category, then recycling of the structure past its lifetime can be direct, without need of chemically separating the original materials.

The performance of the material combination targeting specific applications depends on the interface between the individual components.

THE INTEREST AROUND THE INTERFACE

When attempting to glue things together, the major issue one may face is that the new object – the outcome of different parts being glued together or broken pieces put together again – will break again. This break would often occur at the exact same area where continuity was lost, the interface of the different parts.

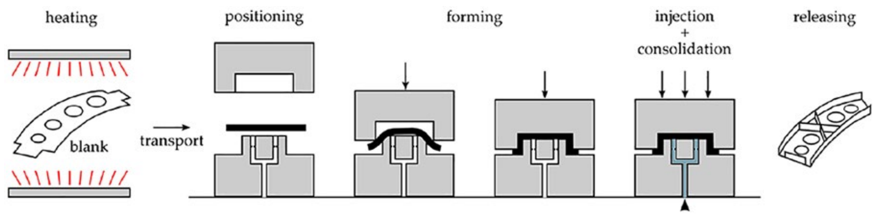


Figure 1. Schematic representation of the overmolding process. Reproduced from Bouwman et al. (2016). https://www.frontiersin.org/articles/10.3389/fmats.2020.00027/full

During the process of overmoulding, two different materials, usually a thermoplastic composite and a polymeric resin, are 'glued' together – not by the aid of glue but by application of heat and pressure. The behaviour of the new structure around the interface between the different materials is of high importance, as it determines its suitability for applications and reliability of the structure. This behaviour can be observed through examination of how strong the physical bonds between the two materials are, as was shown by Prof Remko Akkerman and his colleagues. Prof Akkerman is a full professor in Production Technology at the University of Twente, Faculty of Engineering Technology, in the Netherlands, and scientific director of the ThermoPlastic Composite Research Center (TPRC). His research focuses on lightweight materials for structural applications, with a clear emphasis on processing and performance of composite materials. Prof Akkerman's latest publication provided an in-depth analysis of the overmoulding process using semi-crystalline polymers as model materials, due to their advantageous properties. He and his colleagues focused on the interface and the bond strength of overmoulded complex parts, in an effort

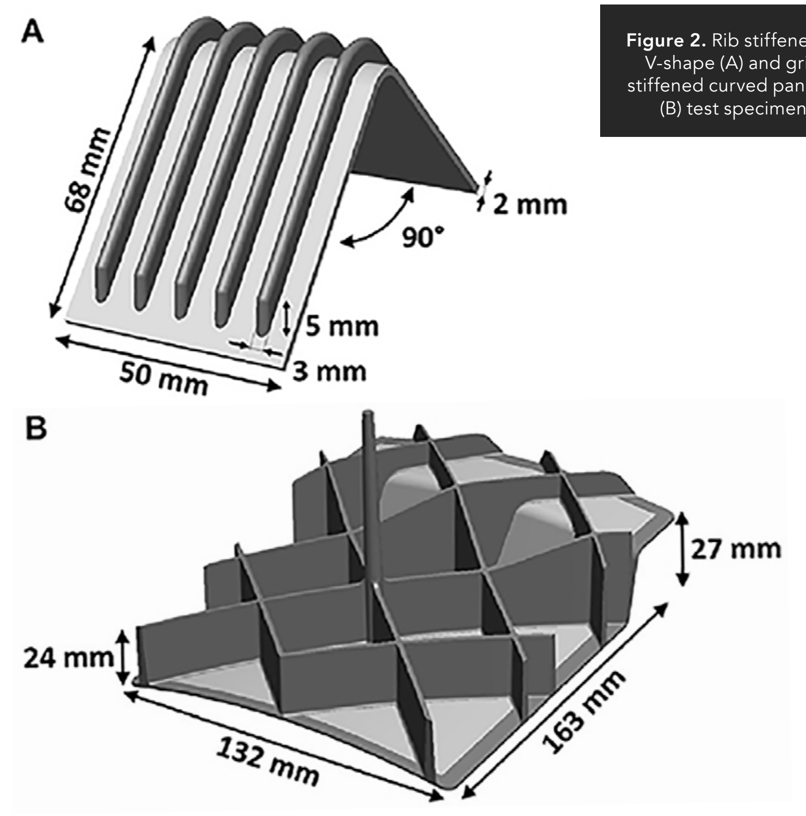


Figure 2. Rib stiffened V-shape (A) and grid stiffened curved panel (B) test specimens.

https://www.frontiersin.org/articles/10.3389/fmats.2020.00027/full

to shed light on the conditions needed for resulting to a functionalised product of sufficient strength.

CREATING DESIGN TOOLS

While the notion of having a mould and using heat and pressure to push one or more materials in it in order to create a new shape can be considered straightforward, the success of the end result is not guaranteed. The performance of the material combination targeting specific applications depends on the interface between the individual components. If the structure is not left to heal properly and physical bonds have not sufficiently developed between the materials used during overmoulding, then its strength might be compromised. The interface temperature should therefore be high enough for a sufficient period of time, to give the molecules the opportunity to diffuse over the original interface. If the area available to transfer loads without breaking the interface is not big enough, this can also lead to reduced ability of the new structure to withstand stress. These parameters were studied by Prof Akkerman and his colleagues, in order to compile information and create design tools that could minimise the requirement for trial and error when designing a new structure with the aid of overmoulding.

Prof Akkerman examined several structures of increasing complexity produced via overmoulding, exploring a range of polymers, temperatures for the injected resin, and the mould, and using a one- or two-step production approach. During the one-step approach the initially flat thermoplastic composite sheet was heated and pushed into the mould just before the polymer resin was injected in the same mould. The two-step approach included an initial step where the heated thermoplastic composite sheet was reformed to the shape of the mould using a press. Then the 3D-shaped, cooled laminate was inserted into the mould, heated, and followed with injection of the resin to create the overmoulded complex structure. The strength of the obtained structures was examined using tensile and shear loading tests, appropriately designed for the geometries and conditions of the specimens under examination. Differential scanning calorimetry was used to identify melting characteristics of the materials.

The experimental results contributed to the formation of a process simulation tool that could be used for the prediction of the structural performance of an overmoulded structure.

The experimental results allowed for better understanding of the overmoulding process and a correlation between input parameters such as temperature(s), degree of healing, or melting behaviour, and the interface strength of the final structure. Furthermore, the experimental results contributed to the formation of a process simulation tool that could be used for the prediction of the structural performance of an overmoulded structure and the effect it could have on the strength of the structure under loading and the possibility of failure. Such a tool could lead to more informed design of moulds and selection of process conditions, subsequently leading to structures of improved strength and minimising the need for trial and error.

TOWARDS BETTER UNDERSTANDING OF THE OVERMOULDING PROCESS

Prof Akkerman's recent publication provides novel insight on the interface strength during overmoulding, building on information previously reported by his colleagues. Thorough research has been conducted for the explanation of the parameters of importance during overmoulding, specifically focusing on strength development and dimensional accuracy of complex structures derived from thermoplastic polymers and polymeric resin composites. This area of research is trying to build a thorough understanding of the process, the importance of the melting behaviour of the polymer, and the healing of the overmoulded structure. Through experimentation and analysis of the results, design tools and process simulation tools can be developed and used for "right-the-first-time" design strategies.

Behind the Research

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https://www.youtube.com/watch?v=T-PJgCPNt9Q

Research Objectives

Prof Akkerman examines optimum process conditions and improved design features for overmoulding, a novel manufacturing process.

Detail

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Remko Akkerman is full professor in Production Technology at the University of Twente, Faculty of Engineering Technology, in the Netherlands, and scientific director of the ThermoPlastic composite Research Center (TPRC). His research focuses on lightweight materials for structural applications, with a clear emphasis on processing and performance of composite materials.

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Collaborators
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Personal Response

What inspired you to conduct this research?

" Lightweight constructions are dearly needed to save weight, energy and CO_2 emissions in significant amounts, provided we can produce these in high volumes. Overmoulding combines the best of two worlds: strong and stiff lightweight thermoplastic composites with complex geometries by injection moulding, while the thermoplastic polymer in both facilitates the short cycle times required for high volume applications. However, as always, the interface between both "components" is crucial for the performance of the combination. It was a good opportunity to figure out the underlying mechanisms as well as a simulation model to describe and predict the resulting structure and performance. "

How could the simulation tool be modified to cover more types of polymers?

" As the model is based on physical phenomena, fairly standard characterisation experiments are sufficient to determine the material property data for any other thermoplastic polymer. Once these are known, the simulation tool can be applied directly to find the part design and processing conditions providing the right or the best interface strength. "