PROCESS DEVELOPEMENT FOR MANUFACTURING HYBRID COMPONENTS USING AN IN-MOULD INFRARED HEATING DEVICE

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Abstract

Large-scale production technologies for hybrid structures are necessary to force lightweight design into automotive applications. The aim of today's research is to find economic strategies for efficient manufacturing processes. This study adresses a process development for manufacturing instrinsic hybrid components using an in-mould infrared (IR) heating device [1].

The consisting concept of an integrated IR-radiator [1] has been developed to improve manufacturing processes for material hybrid components dominated by thermoplastic materials. This approach makes use of a substitution of steel with transparent ceramics at local areas of the mould and an the integration of IR-radiators. Thus, the problem of rapid temperature loss of thermoplastic preforms through direct contact to the cold mould surface can be avoided.

This concept has been build up and comprehensive investigations of its usability has been made. The integration of a heating device enables a reduction of station times by utilizing dead times (interims) for heating processes. This also allows a gentle processing of material. The ceramic-faced surface of the preform can be heated up focussed to necessary processing temperatures at specific times. This research work discusses a process development using an in-mould IR heating device.

1. Introduction

The automotive industry sector pursues various lightweight strategies in dependence of its specified application or target markets. These strategies, such as metal- or FRP-lightweight design, reach their economic limits when trying to exploit the full weight saving potential and the implementation in large-scale production at the same time. Therefore, automotive lightweight design still stands out primarily by fuel savings and CO2 reductions for combustion engines and extended ranges for electric vehicles. This is obviously a necessary reason to drive the development of lightweight design forward, but the potential of lightweight design to solve this problem exclusively on its own is limited. In practise, the fuel reduction value (FRV) shows a maximum of 0.35 l (100 km x 100 kg)-1 [2]. Thus, there must exist further reasons for using new materials with lightweight design. The main benefit of lightweight design and multi-material usage is to generate approaches for innovative components by neglecting conventional construction methods, part boundaries and function attribution while increasing the parts weight.

A promising way to enhance such an economic lightweight design is the approach of material-hybrid design. Hybrid components combine the advantages of different materials as well as material classes in a most efficient way to strengthen essential properties, specifications and additional functionality [3]. Metals, plastics, ceramics and fibres of different types exhibit different advantages that can be applied for a most suitable function integration in the target part. Besides cost advantages, hybrid design enables a material based function integration within lightweight construction and production.

Economic manufacturing processes for hybrid components are necessary to compensate for higher material costs. These production systems must be capable for high degrees of automation and short station times as well as value-adding processes such as injection moulding. [4–7]

In this setting, continuous fibre-reinforced thermoplastics (TP-FRP), metal inserts and injection moulding of short-fibre thermoplastics show beneficial properties. These materials provide the technical potential to improve conventional lightweight design approaches. But due to their widely differing processing properties an intrinsic manufacturing process implicates several challenges. Despite the difficulties of joining technology between metals and plastics, which are not focussed on in this project, the integrated manufacturing process for integral lightweight components is subject of research. In further publications a concept of mould integrated IR radiators has been introduced [1]. It pursues an improvement of heat management of thermoplastic pregpregs in a combined thermoforming and injection moulding process.

2. Integrated processing of primary shaping and forming of thermoplastic composites

In contrast to thermosets, thermoplastics offer advantages even in terms of higher ductility, impact resistance and state of the art large scale production technologies [8]. TP-FRP are provided tailored, pre-impregnated and consolidated as organo sheets or tapes. Processing them opens the possibility of adapting series production technologies to subsequent combined thermoforming and shaping processes, such as injection moulding.

2.1 Process design for manufacturing of thermoplastic prepregs and injection moulding

Thermoforming is a method of forming plastics to final parts under the influence of heat. This process consists of four basic steps beginning with heating up the material up its melting or processing temperature. At this temperature the basic matrix material transforms to a viscous-flexible phase. In this condition the material can be formed into mould under pressure. Finally, the formed material is cooled and demoulded when it gets its primordial condition. [9]

Injection moulding is a manufacturing process with a particularly high degree of industrialization. Its most important benefits are the production speed, the high degree of geometrical freedom and potential for process and functional integration. Its process has some basic steps, like closing the mould, injecting, cooling, metering and demoulding. Injection moulding is a state of the art process for large-scale applications in many industries. [10]

A process combination of both methods enables the production of complex, function integrated and final shaped parts [11,12]. Recent TP-FRP manufacturing technologies include automation solutions to connect the process stations, such as material supply, placement in a mould, component manufacture and extraction [13]. However, these technologies are either limited to processing merely a single material or a single semi-finished part in each cycle. In addition, they are taking the risk of material damage due to temperature impact.

Current research focuses on processing multiple semi-finished parts of various materials in a single cycle to create complex components. Furthermore, research activities struggle with ensuring necessary processing parameters varying for different materials at the same time. The assumed process chain in Figure 1 clarifies this fact. [14,15]

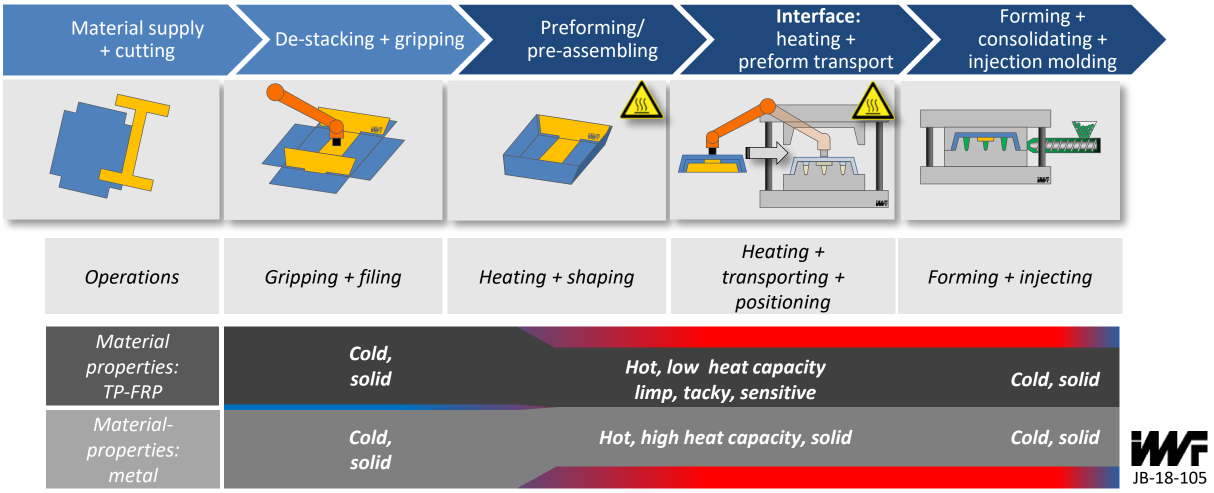

Figure 1. Process chain for manufacturing hybrid components containing combined thermoforming and injection moulding.

The presented process chain contains overlapping individual processes of preparation, supplying, handling-based thermoforming and combined forming and injection moulding. The flow chart below illustrates the various material properties depending on the process temperature (colour gradient blue-red).

2.2 Processing properties of thermoplastic composites

Despite many advantages, the integrative approach of combined processing induces several challenges. These arise from differing material properties at different stages of the process. Figure 1 depicts the material properties of TP-FRP and metal varying during the process. It is to be recognized that the requirements of the process do not always meet those of the material.

- **Temperature control**
  TP-FRP must be processed at temperatures above its melting or processing point for shaping and consolidation. In addition, adhesive bondings of TP-FRP and injected plastics require these temperatures as well. Because of the material behaviour and process requirements it is difficult to reach ideal temperature without damaging the material.
- **Stiffness**
  In a cold state TP-FRP behaves like solid materials and is easy to handle. As soon as the material becomes molten, it shows limp and textile behaviour. Because of this reason a precise handling, transportation and inserting into moulds of cut preforms becomes impossible. Therefore, it is desirable to avoid situations of molten prepregs in open surroundings outside of moulds.
- **Material damage and degradation**
  Molten TP-FRP becomes very sensitive and tacky, which increases the chance of material damages during the process. Simultaneously high temperatures at and above the melting point cause a material degradation, which depends on the period of time and the level of temperature.

2.3 Heat management

The temperature appears as one of the most important parameters in combined processing of TP-FRP with injection moulding. Different approaches, such as in-mould or in-line heating TP-FRP [14] or metal inserts [16,17], have already been introduced. However, the challenging heat management of TP-FRP is still not solved but possible approaches have to be investigated.

A promising approach to reach station times for multi-material lightweight production makes use of the beneficial properties of each material within the process, therefore metal support structures can be used for a multiple functional integration (handling, processability, mechanical properties) [18,14,19]. Especially to solve the challenge of temperature control, the advantagous behavior of metal can be used as a heat storage and shield. But this approach does only work for special use cases as only a local use of metals is aimed for.

Another solution are external heating technologies. Convection or IR-ovens are in common use. The main disadvantage of such a device is the distance to the mould. After reaching the targeted temperature transferring operations involve temperature losses. Even fast and fully automated processes need several seconds of transferring time and cannot avoid these losses.

Heating solutions combined with handling technologies or moving IR-radiators, as shown Figure 2, try to reduce this disadvantage and the resulting problems. But these solutions imply high technical efforts and still have waiting times with temperatures losses. However, many applications for these technological approaches are suitable. In case of increasing geometric complexity and demands on the parts and surface quality, these approaches reach their limits.

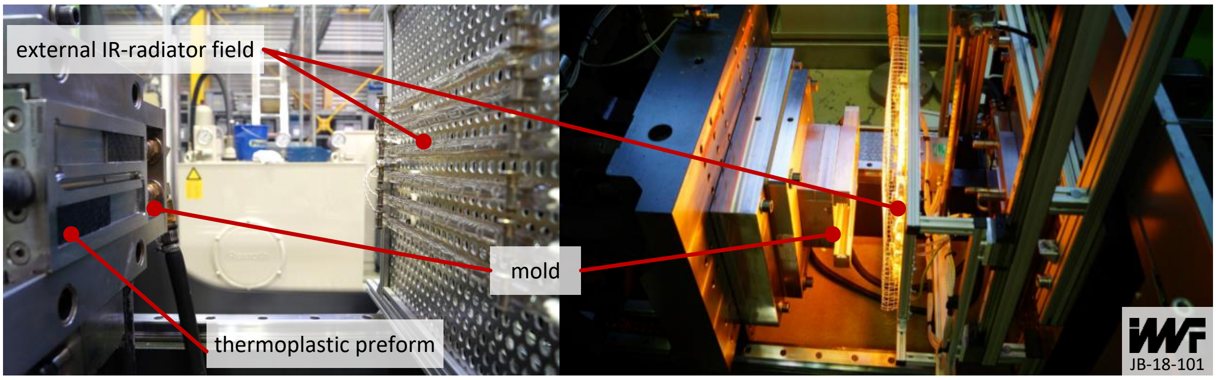

Figure 2: External IR-radiator heats in open mould.

If TP-FRP is heated both with an external device outside of a mould or already inserted, it must be overheated to balance the temperature loss while transferring it into the mould or the device movement outwards of the mould. In this case, the overheating difference to the necessary temperature rises with the bridging time until overmoulding or thermoforming starts. This causes material damages and degradation of the thermoplastic matrix of the preform.

Therefore, this research approach aims at a process development for manufacturing intrinsic hybrid components using an in-mould IR heating device.

3. In-mould IR heating device

In the following section, the in-mould IR heating device will be discussed which will be used for the process development. First results of experimental investigations support the claim of the advantages of the in-mould heating device.

3.1 Concept of an in-mould IR radiator

The main requirement of the new heating approach is to apply conventional, effective, proven and secured heating technologies. It is not the aim of the concept development to invent new heating mechanisms or technologies. The idea is to use a preferred technology and transfer it into new heating device applications. That is why some important technologies such as laser scanning heating are not pursued further. Because of intensive experiences with that technology and many advantages, e.g. efficiency and industrial safety, IR-radiator technology are meant to be used. Its disadvantage of direct visual contact to the target needs to be solved though. [1]

To integrate an IR radiator into a mould several requirements have to be met. First, the radiation needs to distribute homogeneously at the target surface. Therefore, a constant distance between the source of radiation and the TP-FRP has to be guaranteed. Even surfaces facilitate a uniformly distributed radiation. For the development if this functional demonstrator a single lap shear geometry in the mould has been chosen, that a spot distance could be realized. Second, the radiation has to reach the target surface. Thus a material with a IR transmittance and high mechanical strength has to be implemented into the mould between radiator and target surface. A partial substitution of steel with a transparent material created an area that acts like a windows in the closed mould.

For this demonstrator, merely the injection side of the existing mould has been adapted. Conventional double pipe IR-radiators have been integrated into the mould hiding behind transparent tool inserts. The first generation of this demonstrator, that is shown in Figure 3, makes use of spinel ceramics as transparent tool inserts.

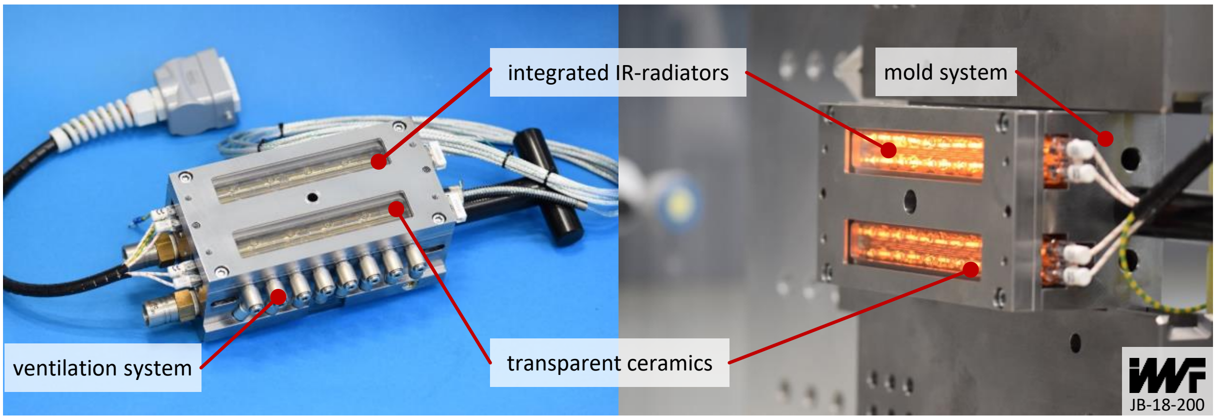

Figure 3: In-mould IR heating device.

3.2 Experimental results

To secure the reliability of the approach of an in-mould IR heating device a comparative study has been made between an internal and external heating process. The measurement of the temperature curves is done at the centre of TP-FRP specimen of PA6GF50, a polyamide 6 with a glas fibre content of 50 %, using thermocouples. The IR-radiators provide a heat input of up to 100 W m^{-2}. As described before a specimen geometry of a basic single lap joint regarding to norm DIN 1465 has been chosen. However, no perfect contact between the surfaces of the specimen and the mould is expectable, the simultaneous occurrence of the high thermal mass of the mould and the high thermal conductivity works therefore like a heat sink. Concurrently, the low thermal conductivity of the polyamide prevents a homogenous distribution of heat within the preform.

Figure 4 shows the temperature curves an in-mould IR heating device (internal) and an external IR radiator field (external). The comparative study of the heating behaviour starts at a same temperature level of about 115 °C. The heating process stops after recognizing asymptotic convergence to 350 °C. This temperature defines the maximum reachable temperature and means either the individual decomposition temperature of the matrix or a balance of heat transfer of the external heating device and the cooling device of the mould. The diagram in Figure 4 exposes the heating times until the lowest possible processing temperature, in this case the melting temperature, is reached. As the target temperature is reached within t_{ext} = 42,9 s using the external IR radiator, the in-mould IR heating device reaches this temperature in only t_{int} = 8,6 s. Taking into account that the use of an external heating device always implies an overheating, the difference between both procedures continues to rise.

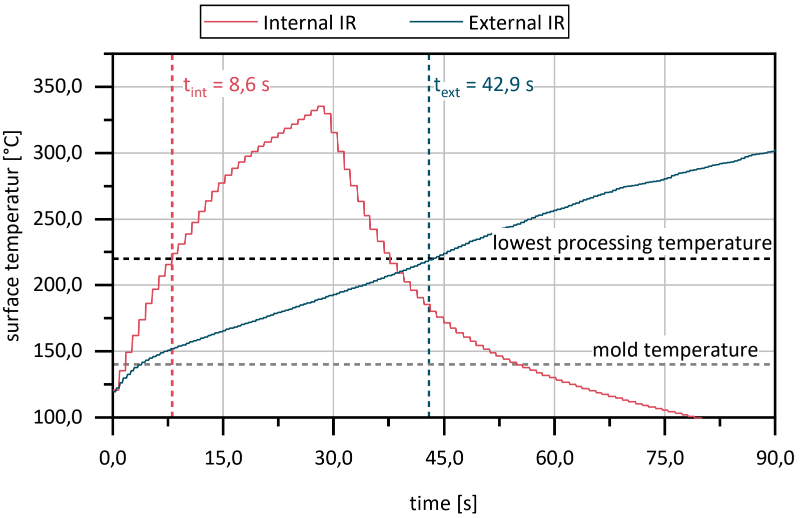

Figure 4: Temperature curves of comparative heating study.

4. Process development for a manufacturing process using in-mould IR heating devices

The results of this investigation and this new heating concept illustrate the potential for efficiency enhancements in manufacturing processes. In-mould heating allows material gentle heating processes because of several reasons:

- **Preventing material damages due avoided overheating**
  In-mould heating allows a process control that connects the end of the heating process directly to the start of the injection process. Thus an overheating gets dispensable and material damages due to handling operations of sensitive materials and material decomposition no longer occur.

- **Utilization of passive cooling time of inserted part**
  After inserting a part up to 20 seconds elapse because of different process steps, such as clearing the machine room and mould closing. Based on the presented investigations this time is sufficient to heat up TP-FRP material to its melting point an above. This period even allows more gently heating strategies with reduced radiated power.
- **Avoiding complex handling operations**
  This approach enables main heating processes within moulds. As a result, external heating stations don’t need to be used anymore to heat the material up to its melting point but can only be used for a pre-heating, what decreases the effort of handling sensitive materials and complex handling tools.

For process development, this means new possibilities in process management with reduced technical efforts.

5. Conclusion and outlook

The investigation of the heating and cooling behaviour shows that the heat management is one key to develop efficient production technologies for multi-material components. This concept approach tries to find a reasonable solution, using conventional and proven heating technologies for TP-FRP in a more process efficient way.

This process gives great opportunities for manufacturing hybrid components and is being built up soon. Hence, future work will focus the development of more complex moulding concepts and the investigatiion of the limitating process boundaries. In addition, other heating concepts, such as inductive, resistance and other radiant heating technologies, need to be investigated towards their in-mould suitability.

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References

[1] Beuscher, J., Schnurr, R., Müller, A., Kühn, M., Dröder, K., 2017. Introduction of an in-mould infrared heating device for processing thermoplastic fibre-reinforced preforms and manufacturing hybrid components, in: , 21st International Conference on Composite Materials, Xi'an, China.
[2] Koffler, C., Rohde-Brandenburger, K. On the calculation of fuel savings through lightweight design in automotive life cycle assessments, in: , The International Journal of Life Cycle Assessment (Int J Life Cycle Assess), vol. 15, pp. 128–135.
[3] Henning, F., Moeller, E. (Eds.), 2011. Handbuch Leichtbau: Methoden, Werkstoffe, Fertigung. Hanser, München, 1255 S.
[4] Cherif, C., 2015. Textile Materials for Lightweight Constructions: Technologies - Methods - Materials – Properties. Springer, Heidelberg/Berlin, Deutschland.
[5] Dröder, K., Herrmann, C., Raatz, A., Große, T., Schönemann, M., Löchte, C., 2014. Symbiosis of plastics and metals: integrated manufacturing of functional lightweight structures in high-volume production, in: , Kunststoffe im Automobilbau, vol. 2014. VDI-Verlag, Düsseldorf, Germany.
[6] Ickert, L., Thomas, D., Eckstein, L., Tröster, T., 2012. Beitrag zum Fortschritt im Automobilleichtbau durch belastungsgerechte Gestaltung und innovative Lösungen für lokale

Verstärkungen von Fahrzeugstrukturen in Mischbauweise, Berlin, Germany 2012. VDA/FAT, Berlin.

[7] Staiger, E., Diestel, O., Cherif, C., Bräunling, S., Hardtmann, A., Großmann, K., 2013. CFK-sheet metal hybrid composites, in: 7th International Textile Conference, Dresden/Aachen, Deutschland.

[8] Mallick, P.K., 2010. Thermoplastics and thermoplastic–matrix composites for lightweight automotive structures, in: Mallick, P.K. (Ed.), Materials, design and manufacturing for lightweight vehicles. CRC Press; Woodhead, Boca Raton, Fla., Oxford, pp. 174–207.

[9] Engelmann, S., 2012. Advanced thermoforming: Methods, machines and materials, applications and automation. John Wiley & Sons, Hoboken, N.J, 335 pp.

[10] Tempelman, E., Shercliff, H., van Eyben, B.N., 2014. Injection Molding of Thermoplastics, in: , Manufacturing and Design. Elsevier, pp. 121–156.

[11] Heim, H.-P. (Ed.), 2016. Specialized injection molding techniques. William Andrew is an imprint of Elsevier, Oxford, United Kingdom, 1 online resource.

[12] Reynolds, N., Balan Ramamohan, A. High-Volume Thermoplastic Composite Technology for Automotive Structures, in: , Advanced composite materials for automotive, vol. 2014, pp. 29–50.

[13] Seidel, S., 2015. Anforderungsrechte, thermoplastische Preforms für den Hochleistungsleichtbau. Zugl.: Bayreuth, Univ., Diss., 2014. TuTech Verl., Hamburg, 175 pp.

[14] Beuscher, J., Schnurr, R., Müller, A., Kühn, M., Dietrich, F., Dröder, K., 2016. Introduction of approaches for in-line heating thermoplastic preforms for manufacturing hybrid components, in: 7th International Symposium on Composites Manufacturing for High Performance Applications, Braunschweig, Deutschland.

[15] Lippky, K., Kreling, S., Dilger, K., Beuscher, J., Schnurr, R., Kühn, M., Dietrich, F., Dröder, K., 2016. Integrierte Produktionstechnologien zur Herstellung hybrider Leichtbaustrukturen. Lightweight Design 9 (2), 59–63.

[16] Thurner, F., Lammel, C., 2014. ProVor - Produktionstechnologie zur Vorkonfektionierung von FVK-Metall-Hybriden: Teilprojekt: Induktive Erwärmung ; Forschungscampus: Open Hybrid LabFactory e.V. ; Schlussbericht ; Berichtszeitraum: 15.03.2013 bis 14.03.2014. IFF GmbH; Technische Informationsbibliothek u. Universitätsbibliothek, Ismaning, Hannover, 24 pp.

[17] Zülch, M., 2011. Temperierung von Spritzgusswerkzeugen durch vollständig integrierte induktive Beheizung. IKFF, Stuttgart, Getr. Zähl.

[18] Beuscher, J., Brand, M., Schnurr, R., Müller, A., Kühn, M., Dietrich, F., Dröder, K. Improving the processing properties of hybrid components using interlocking effects on supporting structures, in: , ECCM17. 17th European Conference on Composite Materials, Munich, Germany, 26-30th June 2016.

[19] Dröder, K., Schnurr, R., Beuscher, J., Lippky, K., Müller, A., Kühn, M., Dietrich, F., Kreling, S., Dilger, K., 2016. An integrative approach towards improved processability and product properties in automated manufacturing of hybrid components, in: Euro Hybrid Materials and Structures 2016, Kaiserslautern, Deutschland.