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# MK$^2$—A novel assembly injection molding process for the combination of functional metal surfaces with polymer structures

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ABSTRACT

The scope of this paper is a new production technology for metal/polymer-composite parts. Based on the assembly injection molding technology a so called MK$^2$-composite is fabricated of a thin functional metal surface layer, a thermoplastic base layer for the mechanical stability and an intermediate layer made of a thermoplastic elastomer (TPE). This creates a bond between metal and thermoplastic layer on the one hand and allows a reduction of thermally and mechanically induced internal stresses on the other hand. In order to achieve an optimum adhesion, an in-line Openair® plasma treatment was integrated into the process, reducing the process chain length to a minimum compared to state-of-the-art bonding processes using reaction adhesives. The performance of the MK$^2$-composite was investigated regarding design and process relevant parameters.



## 1. Introduction

### 1.1. Background

Assembly injection molding allows cost-efficient mass production of highly integrated functional parts, combining at least two components consisting of different or identical materials of which at least one can be processed by means of polymer injection molding. The components are simultaneously assembled inside the mold with the forming process (Schmachtenberg et al., 2007). This opens up numerous opportunities for the reduction of process steps and the implementation of innovative and highly integrated products (Michaeli and Lettowsky, 2004). This facilitates a high potential to increase process reliability and cost-saving (Schuck, 2008).

Metal and plastic integrated multilayer composites are state-of-the-art and can be found in a number of applications, e.g. decorative interior parts in the automotive industry giving a good visible and haptic performance. Usually the layers are connected by either tight or form fitting or by using a reaction adhesive in an additional bonding process (Ehrenstein, 2007). Joining polymer and metal parts directly by injection molding is usually not possible, as in general no or only an insufficient adhesion can be achieved (Ehrig, 2007). Only costly pretreatment of the metal surface, such as cleaning, degreasing and application of an additional adhesive coating, can lead to the improvement of the bond strength (Al-Sheyyab et al., 2007; Grujicic et al., 2008a). If sufficient adhesion is achieved, polymer shrinkage and different thermal elongation of metal and polymer can result in residual stresses at the polymer–metal interface which can reduce the bond strength and the durability significantly (Ramani and Zhao, 1997). In addition to that, the inhomogeneous thermal elongation in a direct connection of thermoplastic polymer and metal increases shrinkage and leads to component warpage (Grujicic et al., 2008b).

### 1.2. Surface effects of plasma pretreatment

When using plasma for surface treatment four major effects can be observed (Liston et al., 1993): (a) surface cleaning, e.g. the removal of organic contamination from surfaces; (b) ablation of material from the surface, which can remove a weak boundary layer; (c) cross-linking or branching of near-surface molecules, which can cohesively strengthen the surface layer; and (d) modification of surface's chemical structure, which can occur during plasma treatment itself and upon re-exposure of the treated part to air, while residual free radicals can react with atmospheric oxygen or water vapour. Generally all these effects will be present to a certain degree. Single effects can prevail depending on the substrate and the gas chemistry, the plasma reactor design and the operating parameters.

On a metal surface the effects of the removal of organic contamination and the reduction of a weak boundary layer are the primary purposes using plasma pretreatment (Knospe, 2007). Furthermore,

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Kim et al. (2003) have revealed that on atmospheric plasma treated metal surfaces new particles could be aggregated densely on the surface, e.g. carbon, oxygen or metal oxides. This can have also positive effects on the polymer/metal adhesion. In addition to that, the plasma treatment on a premolded polymer part results in an activation and modification of the surface's chemical structure by formation of functional groups, e.g. –OH or –NH (Schüßler, 2008). The surface activation and modification are the most important effects to realize or to increase the adhesion between two polymers in an assembly injection molding process (Schuck et al., 2008).

In this paper, an approach is presented that allows the combination of metal and polymer components by means of assembly injection molding. Instead of an additional external and costly pretreatment step, an elastic intermediate layer is injected which generates sufficient adhesions between the metal surface on one side and the thermoplastic base layer on the other side. This is achieved by an integrated surface treatment with Openair® plasma. In addition, the flexible TPE interlayer is capable of compensating the mechanically or thermally induced stresses.

## 2. The MK$^2$-process

MK$^2$-composites consist of three components: A thermoplastic base layer and a comparatively thin (0.5–1 mm) metal surface layer on top. To assure a sufficient adhesion between the metal surface layer and the base layer as well as to compensate mechanical and thermal stresses an additional intermediate layer consisting of a thermoplastic elastomer needs to be injected, Fig. 1.

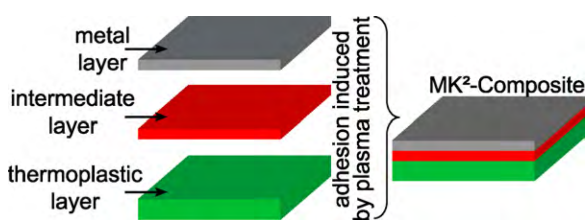


**Fig. 1.** Structure of a MK$^2$-composite.

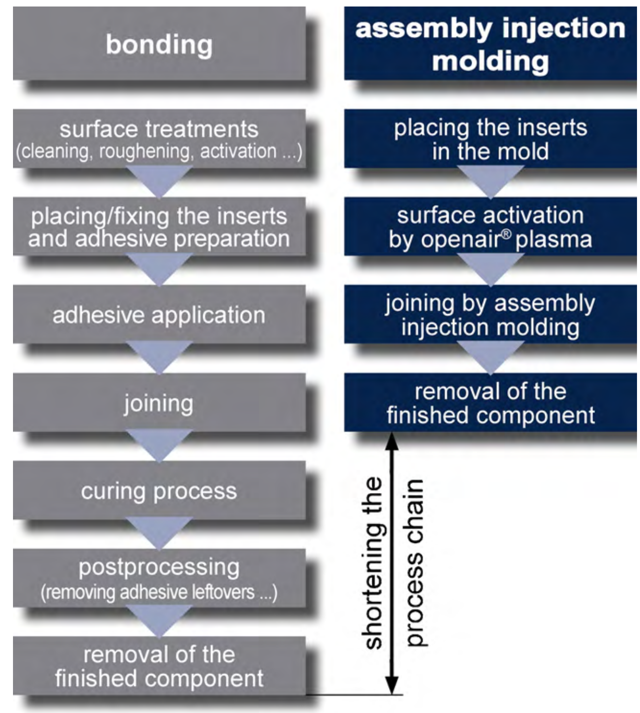


**Fig. 3.** Reduction of the process chain in the MK$^2$-process compared to conventional bonding technologies.

To assemble the MK$^2$-composite, the thermoplastic base layer can either be inserted into the mold together with the metal layer as a precast part or directly injection molded using a core back or rotary table mold, which allows even higher productivity. Subsequently, a surface pretreatment by Openair® plasma is made. Both layers are treated on the joint surfaces inside the open mold. After plasma treatment, the mold is closed and the intermediate layer is injected right between the base and the surface layers, Fig. 2.

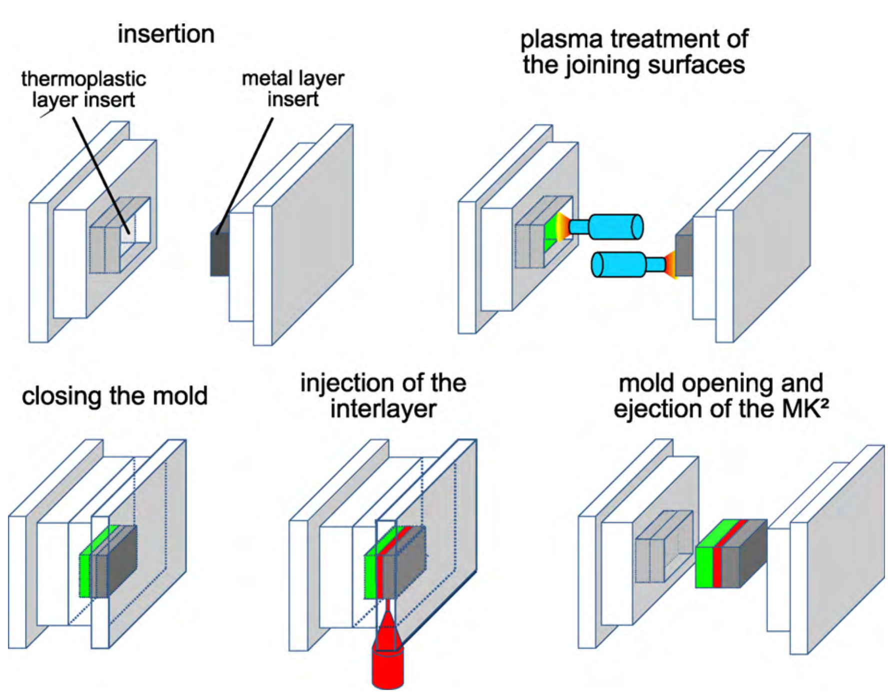


**Fig. 2.** Injection molding cycle of the MK$^2$-process.