Quality Assurance in the Production of Semi-Finished SMC and BMC

Gisela Lanza, Stefan Stockey# and Anna Ertel

Karlsruhe Institute of Technology (KIT), wbk Institute of Production Science, Kaiserstr. 12, 76131 Karlsruhe, Germany
Corresponding Author / E-mail: stockey@wbk.uka.de, TEL: +49-721-608-44016, FAX: +49-721-608-45005

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Fiber-reinforced plastics like sheet molding (SMC) or bulk molding compounds (BMC) offer the ability to reduce the overall weight of products for individual as well as public transportation concepts like motorcars, buses and trains without decreasing passenger safety. A fundamental obstacle on the way to lightweight mobility can be seen in the total production costs of fiber-reinforced plastics. Beside the continued automation of the production processes, advanced quality assurance also offers several chances for contributing to cost reduction efforts. The first approach presented in this paper should focus on the avoidance of producing scrap by providing a systematic method for the quality assessment of produced semi finished SMC/BMC batches. This assessment is processed by the calculation of a quality index and its transformation into the degree of fulfillment. Based on the degree of fulfillment, it can be determined if the produced semi-finished SMC/BMC batch is deliverable to the customer (or to the next process step).

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NOMENCLATURE

a = actual value
d = maximum deviation
qi = quality index
t = absolute tolerance limit
w = weighting factor
x = nominal value

1. Introduction

One of the most important aspects of modern lifestyle can be seen in individual mobility and transportation within urban and suburban spaces. Regarding the rate of urbanization within Asian countries, especially in China or India and the limited availability of fossil fuels, one of the main challenges can be seen in the reduction of fuel consumption in combination with lower carbon dioxide emissions by reducing the weight of the vehicle [1]. The constantly rising demand of lightweight parts by the car manufacturing companies caused great efforts in developing new composite materials [2]. The usage of weight-optimized vehicle parts, made of sheet molding (SMC) or bulk molding compounds (BMC) of fiber reinforced plastics, can be considered as a suitable way to improve the weight of the vehicle without decreasing passenger safety. Due to their excellent mechanical, chemical and physical properties, such as high rigidity and surface finish, SMC and BMC can be used in a wide range of parts for products within the individual and public transportation sector (Figure 1).

Fig. 1 Example for an application of lightweight parts (seat shell made of SMC) in a railway car [2]

In addition to the application of fiber reinforced plastics in vehicles with a conventional power train, lightweight parts in general can be seen as an enabling technology for the electrification of mobility. The success of hybrid or fully electrified car concepts depends on the transportation range that can be achieved on a single battery charge. However, there is still one obstacle, which has to be overcome in order to establish fiber reinforced plastics for an application within private or public mobility sector: the costs per produced part [3]. A high-graded automation of the production process as well as the reduction of scrap can lead to a cost effective production of fiber reinforced plastics. Therefore the quality assurance can offer a significant contribution by an automated controlling of all steps within the production to prevent the processes from producing scrap. To start at the beginning of the process chain, the first approach should focus on quality assurance within the production process of the semi-finished material itself. The focus of this paper is therefore the production process and quality assurance of semi-finished sheet molding and bulk molding compounds.

2. Production Process of Sheet Molding and Bulk Molding Compounds

2.1 Sheet Molding Compounds

Sheet Molding Compounds consist of duroplastic resins, textile-glass fibers and mineral filler as well as additives like thickening agents. In general, the SMC is a fiber reinforced plastic composite, which can be brought to a freely definable three-dimensional shape by applying a static pressure in combination with high temperature to the semi-finished material within a hot press. The basic material for the hot-pressing process is a mat consisting of the resin-fiber compound between an upper and a lower foil.

The production process of a semi-finished SMC is illustrated in Figure 2. The first production step is the preparation of the resin by a metering and mixing process of the different ingredients.

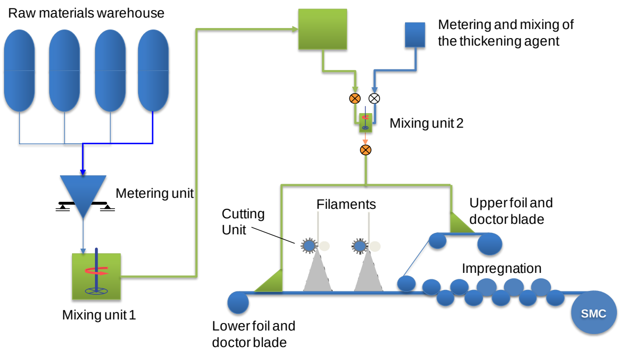

Fig. 2 Production process of the semi-finished SMC [2]

After the resin is mixed with the thickening agent and applied to the upper and lower foil by two doctor blades within the next process step, the fiber-glass filaments are chopped by a cutting unit above the lower foil. Finally the upper foil is carried to the lower foil, after the chopped fibers fall down to the lower foil. The embedding of the glass fibers into the resin matrix is ensured by the impregnation process, in which an external pressure is brought to the SMC mat by a roller mill. The manufacturing process in which the semi-finished SMC is transferred to its final shape for the usage as an assembly part is shown in Figure 3. The processing temperature while hot-pressing the final part is about 130-170° C in combination with a pressure of approx. 50-100 bar.

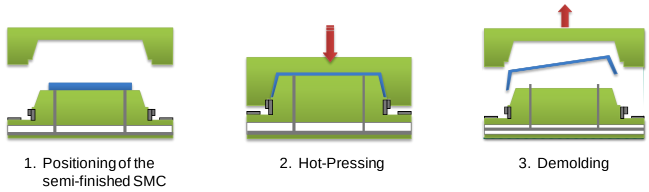

Fig. 3 Manufacturing process (hot-pressing) of the SMC part [4]

2.2 Bulk Molding Compounds

Bulk molding compounds are widely made of the same ingredients as sheet molding compounds. Some essential differences can be seen in a larger amount of filler and shorter glass fibers (approx. -50% compared to the SMC fibers). The larger amount of filler leads to an increased viscosity of the BMC. Therefore the production process of semi-finished BMCs is slightly different from the production process of semi-finished SMCs (Figure 4). The glass fibers are pre-cut and directly given into a special kneading machine to the resin. The increasing viscosity while adding filler to the resin leads to the restriction, that only 1/3 of the intended filler mass of the final product can be directly added in the metering unit. The remaining 2/3 of the intended filler mass has to be added to the resin within the kneading machine.

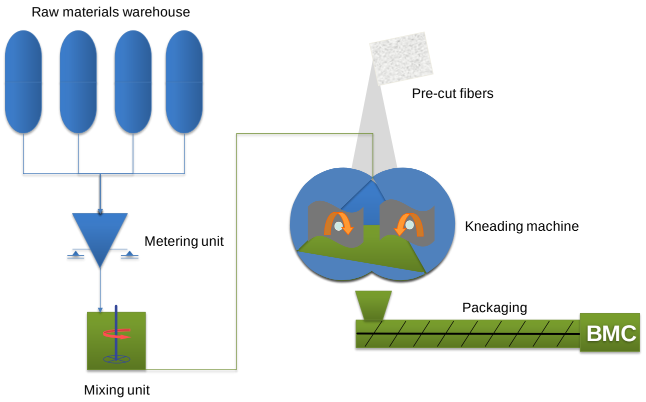

Fig. 4 Production process of the semi-finished BMC [4]

Semi-finished BMC is mostly used for casting parts via injection molding. The single process steps of the manufacturing process using injection molding are shown in Figure 5. By using semi-finished BMC with shorter glass fibers, it is possible to produce thin-walled parts. Short cycle times and material cost advantages can also be achieved by using BMC.

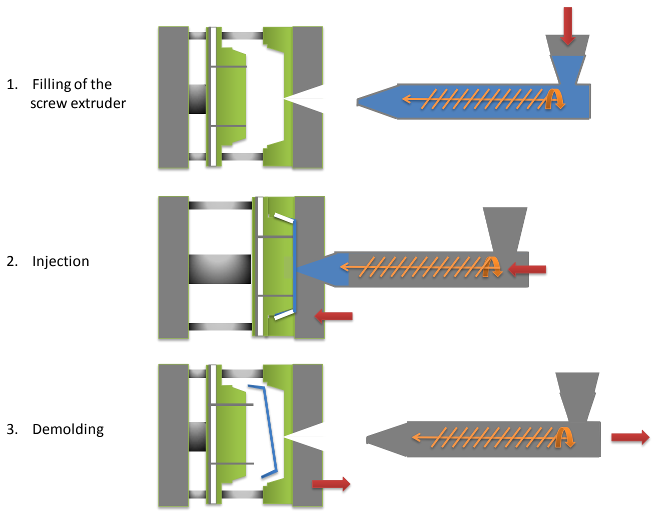

Fig. 5 Manufacturing process of BMC-parts via injection molding [4]

3. Quality Assurance of Semi-Finished SMC and BMC

3.1 Quality Attributes in the Production of Semi-Finished SMC and BMC

As mentioned in the introduction, the quality assurance offers some chances to reduce the costs of fiber reinforced plastics by preventing the production processes from producing scrap. The important values, which have an impact on the characteristics and on the quality of the SMC and BMC, should be considered first. The main quality attributes for a semi-finished SMC are as follows [2]:

- Weight per unit area
- Plasticity (Viscosity)
- Density
- Fiber impregnation
- Glass content
- Shrinkage
- Homogeneity of the mixing

The weight per unit area [g/mm²] is nearly the most important quality attribute of the semi-finished SMC. If the weight per unit area differs from the nominal value, some irregularities can take effect during the hot pressing process of the final part. On the one hand, there can be lesser material within the tools of the hot press, so the final part may have some defects caused by cavities. On the other hand, if the actual weight per unit area is larger than the nominal value, material may flow over the tool limits. The plasticity/viscosity is also meaningful regarding the fiber impregnation and automated handling of the SMC. Considering the stability and strength of the final part, the total concentration of glass-fibers comes into focus. Furthermore the shrinkage is also an important factor for the final part, though it is not measureable on the semi-finished SMC (only by a test mold using a hot press).

The quality attributes of a semi-finished BMC are rather different than the ones of the SMC. The main attributes are the plasticity, measured in kilonewton (kN), and the reactivity. If these attributes differ from their nominal value, the final part may be porous (caused by a different plasticity) or the cycle times may change (caused by changes of the reactivity).

3.2 Quality Assessment of Semi-Finished SMC and BMC

In order to prevent the subsequent manufacturing processes from producing scrap, the semi-finished material batches need to be evaluated according to the aforementioned quality characteristics. Therefore an individually calculable quality index (qi) for each SMC/BMC batch was developed at the Institute of Production Science (wbk). The demand for the assessment of a complete SMC/BMC batch by using only one parameter can be seen as the main reason for the development of the integrated quality index. This index is based on the addition of the relative deviation of the single quality attribute from its nominal value and it is calculated as shown below:

$$qi = \sum_{u=1}^{v} \left(w_u * \left| \frac{x_u - a_u}{x_u} \right| * 100 \right)$$

The quality index is dimensionless; a conclusion can only be given by the transformation into the degree of fulfillment using a corresponding scale. The upper limit of the quality index scale (equates 0% on the degree of fulfillment scale) has to be set up using the following expression:

$$qi_{max} = \sum_{u=1}^{v} \left(w_u * \frac{|x_u - t_u|_{max}}{x_u} * 100 \right)$$

In case there are both upper and lower specification limits of a quality attribute, only the maximum range between the nominal value (x) and the upper or lower tolerance limit (t) should be taken into consideration. To receive reliable results, the upper limit of the scale has to be recalculated for every type of product, even if the changes are marginal. The weighting factor (w) of each quality attribute can be set up freely, related to the quality request of the customer. A suitable way to determine the weighting factor under the restriction of reproducibility is a pairwise comparison of the attributes as shown in Figure 6. In this Figure, the value two means, that the attribute “Basic weight” on the left side is more important than “Viscosity” on the top. If both attributes are equal, the value has to be one.

	Basic weight	Viscosity	Shrinkage	Reactivity	Density	Weighting factor
Basic weight	-	2	1	2	2	7
Viscosity	0	-	1	2	2	5
Shrinkage	1	1	-	2	2	6
Reactivity	0	0	0	-	1	1
Density	0	0	0	1	-	1

Fig. 6 Pairwise comparison of the quality attributes to determine the weighting factor

In general, the produced batch of semi-finished SMC/BMC obtains a better quality rating, the lower the value of the quality index is. This fact can also be seen in Figure 7, in which a degree of fulfillment of 100% is equal to a quality index of zero.

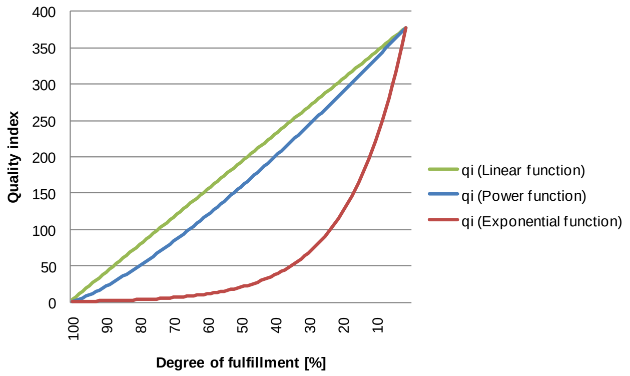

Fig. 7 Correlation of the quality index (qi) and the degree of fulfillment using different basic functions

Depending on the quality objectives of the producing company, a linear, power or exponential function can be used to transform the quality index into the degree of fulfillment. The usage of the linear function leads to a moderate estimation of the product quality. In contrast to the linear function, the exponential function is stricter. For example a quality index of 50 equals a degree of fulfillment of 90 % (linear function) respectively 35% (exponential function). Using the quality index for the estimation of a produced SMC/BMC batch, the decision whether a batch can be delivered to a customer or has to be marked as scrap can be made in a systematic and reproducible way.

3.2.1 Visualization of the Relative Deviations from the Nominal Values for the Single Quality Attributes

An additional, simplified visualization of the relative deviation for the quality attributes from their nominal values can be achieved by using a spider chart (Figure 8). In contrast to the calculation of the integrated quality index, which is accumulating the separate quality attributes into one parameter, the spider chart is providing a view on the actual quality state of each single attribute in relation to its tolerance.

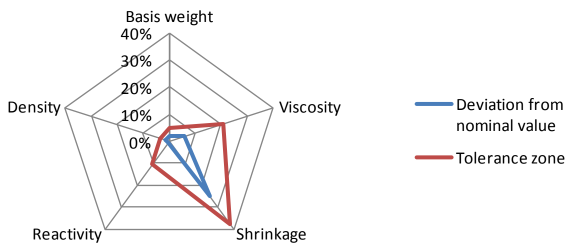

Fig. 8 Visualization of the relative deviations and tolerance zone for example quality attributes

As can been seen, the tolerance zone is marked by the red line and the actual deviations from the nominal value of each attribute is marked by the blue line. The maximum acceptable deviations (relative tolerance limits) in Figure 8 are calculated in the following way:

$$d_{u,max} = \frac{|x_u - t_u|_{max}}{x_u} * 100$$

If the blue line in Figure 8 crosses the limits of the relative tolerance zone, the SMC/BMC batch is out of tolerance and should be labeled as scrap.

4. Summary and Further Scientific Work

The approach presented in this paper offers a systematic method for the quality assessment of semi-finished SMC and BMC by calculating a quality index based on the aggregation of different quality attributes. Furthermore the obtained quality index is transformed to the degree of fulfillment which can be used to decide whether a batch is deliverable to the customer or to the next process step or if it has to be labeled as scrap. With the application of this method to the quality assurance system within the production of fiber reinforced plastics, a continuous observation of the product quality can be achieved from the beginning of the process chain. Due to the avoidance of producing parts outside of the tolerance limits, the total production costs can be reduced significantly.

Further scientific work should focus on the availability of consistent and actual data, which is directly provided by the production processes to ensure the functional capability of the presented approach. So the applied measurement principles as well as the related measurement equipment for an inline quality assurance should be set in focus.

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