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Verification of deformation and loading of a mould during manipulation

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Abstract. One of the methods of fabrication of artificial leathers in the automotive industry is the so called „slush" technology. It is based on powder sintering in a mould. The mould is loaded thermally during the production cycle and mechanically when manipulated. As cracks had occurred in the mould, it was necessary to verify, whether the cause of the crack initiation was thermal or mechanical loading. The aim of the first stage of verification was theoretical computation and measurement of the real mould loading during manipulation. The paper describes the methods of computation and measurement.

Introduction

The artificial leathers are used in the automotive industry as final surface layers of many interior parts. One of the possibilities is powder sintering in a mould. This technology is based on application of the powder material on the surface of the mould. Heating the mould up to a few hundred degrees centigrade results in melting the powder, thus producing the required part. The finished product is then removed from the mould and the mould is cooled down to the normal temperature. Then it is cleaned of the powder residue and the whole cycle is repeated. To improve efficiency, the mould is designed to produce two parts at the same time. Considering large dimensions of some parts (e.g. leathers for switchboards), the mould is bulky and heavy. Therefore the entire manipulation is performed by a robot. The mould fixed on the robot during manipulation is in the Fig.1.

Fig.1: Manipulation with a mould

During the industrial process cracks occurred in the mould. As the mould is loaded thermally in the production cycle and mechanically during manipulation, it was necessary to identify causes of the crack initiation. In the first stage it was required to identify the magnitude of mechanical loading of the mould during its manipulation. This stage is divided in two steps. At first the loading was simulated on a mould model by means of the FE analysis. Coming out of the results, some points and directions of maximum stress during manipulation were predicted. Strain gauges were installed at these points and the calculated values were then verified in the second step by measurements during real mould manipulation. Another sense of the verification measurement was to find out, whether the real operation corresponds to the presumptions. The mould might be excessively loaded for example during the storage in badly adjusted clump fixtures.

FE analysis

For the simulation purposes it was supposed, that the mould was loaded during the manipulation by multiple effect of fields of forces in several directions. The system of coordinates had been selected so that the axes x and y lay in the plane of the mould flange and the axis z was perpendicular to it. The effect of acceleration of 5G in these axes was simulated, additionally in the three-dimensional vector inclined under the angle 45° to all the axes. This simulation resulted in identification of the point of maximum stressing of the mould and definition of the directions of the main stresses at these points (Fig.2). Afterwards strain-gauge rosettes were installed at these points according to the directions of the main stresses, in order to verify the values during real manipulation.

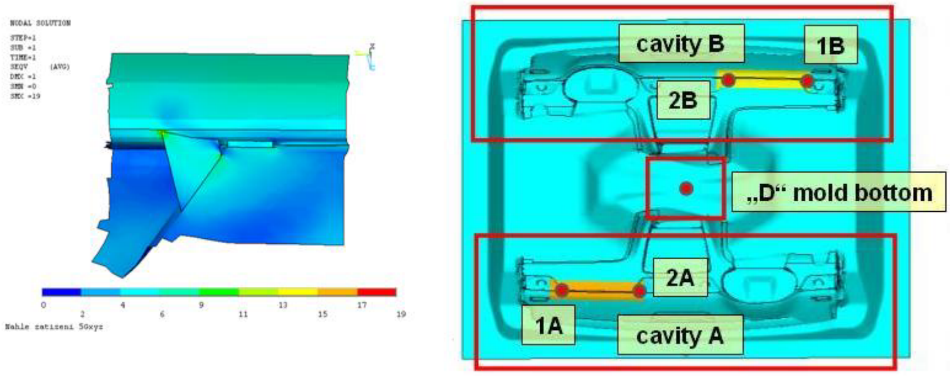

Fig. 2: Example of results of FE analysis and distribution of points of maximal stress

The results of the analysis showed that maximum magnitudes of the stress σ_{HMH} originating in the mould were in the interval 5 to 10MPa. Such values are considerably small and by no means can be the primary cause of the crack initiation.

Verification measurement

For the verification measurement there were three-axial strain-gauge rosettes HBM 1-RY91-6/120 installed at the predicted points of the mould. Their orientation had been defined on the basis of calculated main directions of stress in the FE analysis (Fig.3).

The rosettes were applied in order to be able to determine the real direction of the main stress in case the results of the FE analysis were not entirely precise. There was one more uniaxial strain gauge HBM 1-LY11-6/12 installed then in the centre of the mould bottom. Individual grills of the strain gauge rosettes were connected as quarter-bridges to the logger DEWE5000. Completion and balancing of the bridges was realized by means of internal resistors of the input module of the logger. Thermally uncompensated connection of the strain gauges was sufficient for this measurement. Manipulation time is only in tens of seconds and no change of the mould temperature occurs during that time. To convert signals to relative strain ε, k-factors given by the producer of the strain gauge rosettes were used.

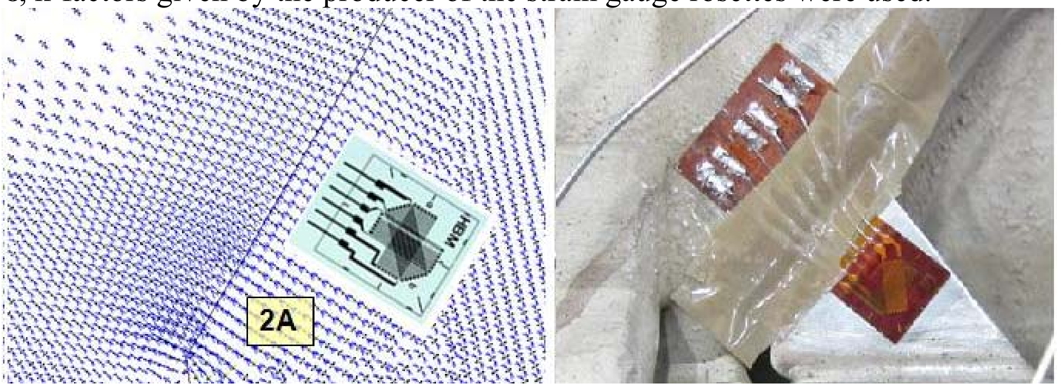

Fig. 3: Analysis of strain directions and installation of strain-gauge rosette at the point 2A

Following the strain gauge installation, the mould was placed in the production line and gradually five manipulation operations were executed: deposition in the extracting station, placing on the slush plate, clamping and unclamping the mould into/from the swivelling mechanism, clamping and unclamping of the inner bucket and clamping into the pre-heating station. For each manipulation independent time-record of the signal was registered.

Processing of measured data

From three signals of one strain gauge rosette the maximum and minimum strain at the given point can be calculated (Eq.1, Eq.2).

$$\varepsilon_1 = \varepsilon_{\max} = \frac{1}{2}(\varepsilon_a + \varepsilon_c) + \frac{1}{\sqrt{2}} \cdot \sqrt{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_b - \varepsilon_c)^2} \quad (1)$$

$$\varepsilon_2 = \varepsilon_{\min} = \frac{1}{2}(\varepsilon_a + \varepsilon_c) - \frac{1}{\sqrt{2}} \cdot \sqrt{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_b - \varepsilon_c)^2} \quad (2)$$

By means of the elastic modulus E and Poisson constant ν (Eq.3, Eq.4) the values of maximum and minimum stress σ can be then determined.

$$\sigma_1 = \sigma_{\max} = \frac{E}{(1-\upsilon)} \cdot \frac{(\varepsilon_a + \varepsilon_c)}{2} + \frac{E}{\sqrt{2}(1+\upsilon)} \cdot \sqrt{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_c - \varepsilon_b)^2} \quad (3)$$

$$\sigma_2 = \sigma_{\min} = \frac{E}{(1-\upsilon)} \cdot \frac{(\varepsilon_a + \varepsilon_c)}{2} - \frac{E}{\sqrt{2}(1+\upsilon)} \cdot \sqrt{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_c - \varepsilon_b)^2} \quad (4)$$

To evaluate possibility of occurrence of plastic deformations in the investigated areas, the HMH hypothesis was applied. Thus from the acquired values σ_1 and σ_2, the magnitude of the equivalent stress σ_{HMH} was obtained. (Eq.5)

$$\sigma_{HMH}(t) = \sqrt{\sigma_1(t)^2 - \sigma_1(t)\sigma_2(t) + \sigma_2(t)^2} \quad (5)$$

Relative elongation measured by a uniaxial strain gauge on the bottom of the mould was converted to the stress by means of a simple relation (Eq.6)

$$\sigma_T(t) = E\ \varepsilon_T(t) \quad (6)$$

In this way the time behaviour of σ_{HMH} during the individual steps of manipulation was calculated from the measured time dependencies of the relative elongation ε for each measured point.

Results

The time behaviour of σ_{HMH} for all types of manipulation was displayed graphically. It was proved that no stress that could give rise to the crack initiation arisen during the manipulation. At the same time it confirmed the results of simulations. Out of four types of manipulation the largest stress occurs during fixing the inner bucket (Fig.4). It is practically the same on the both sides of the mould and does not exceed 17MPa.

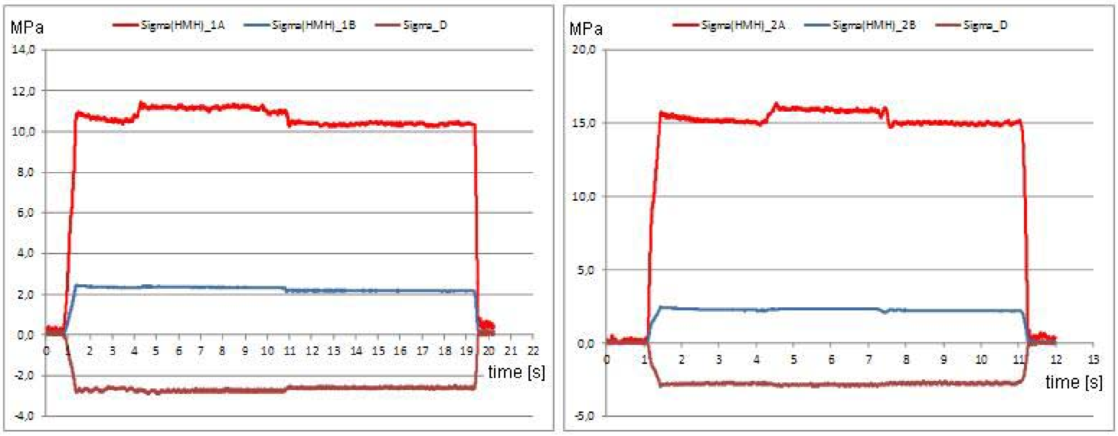

Fig. 4: Time behaviour of σ_{HMH} at measured points when fixing the inner bucket

The measurement simultaneously proved that the results of simulation corresponded to the reality. Maximum measured values σ_{HMH} for all types of manipulation are in the Table 1.

Type of manipulation	max σ_{HMH}
Deposition in the extracting station	1,6
Placing on the sintering table	5
Clamping into the swivelling mechanism	4
Clamping of the inner bucket	17
Clamping into the pre-heating station	5

Table 1: Maximal values of σ_{HMH} for individual types of manipulation

Conclusion

Simulation by means of the FEM analysis predicted, that the values of mechanical loading of the mould during manipulation are too low to cause cracks in the mould. Practically realized verification measurement confirmed that in real service there is no sudden loading of the mould caused by incorrectly adjusted fixing elements. Probable cause of the crack initiation might be thermal straining during the production cycle. It was recommended to continue with analyses and practical measurements of thermal loading of the mould.

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