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Definition of Effective Material Properties of Recycled Plastic: Image Analysis and Homogenization

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Abstract: The influence of foaming agent on the properties of steel-reinforced beams made of recycled plastic material is studied in the paper. The foaming agent creates a porous core in the recycled plastic elements, which must be reflected when deriving the effective properties to be used in macroscopic simulations. To that end, standard image analysis combined with nanoindentation and the Mori-Tanaka micromechanical model will be adopted to identify elastic material properties of the plastic material both inside and outside of the core. These are expected to enter an independent macroscopic analysis of the steel-bar reinforced beams.

Introduction

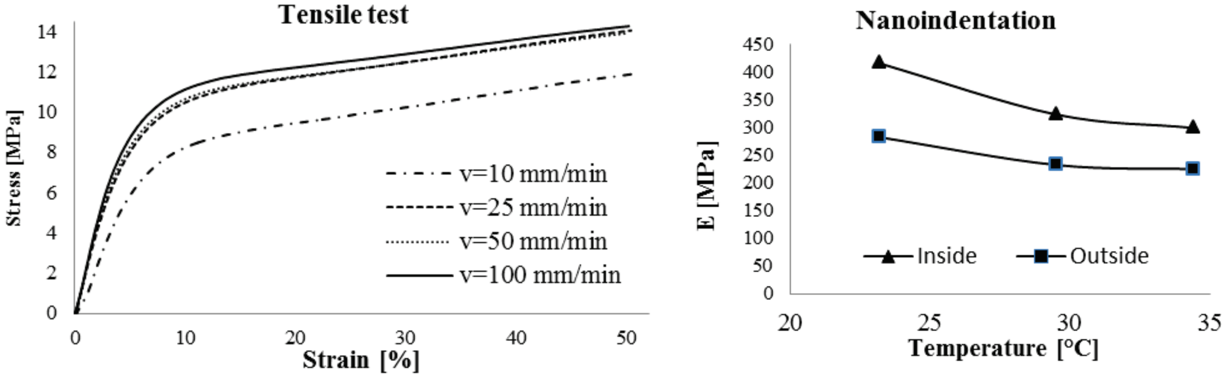
An ever-increasing amount of plastic waste is a global problem with negative impact on our natural ecosystem [1]. A mechanical recycling process means that the plastic is melted only by heat and pressure and no intermolecular connections are created. The resulting recycled material is then a mixture of plastics with lower material properties than the original material and therefore a novel combination with steel reinforcement was developed. The use of recycled plastic in new structures promises the possibility of turning large amounts of plastic waste into sustainable construction. Hence, it is imperative to understand the structural properties of steel reinforced recycled plastic beams so that their capacity can be exploited while extending their application.

Production

The recycled plastic products are typically produced by injection process. Cut pieces of assorted plastic waste are heated to 200˚C. Under this temperature the plastic becomes liquid and then is pressed into a steel mold of a required shape. In the case of steel reinforced beams, the steel bars are placed in the mold ahead of injection of the plastic melt. The liquid plastic is then injected into the mold from one end and the beam is filled along its entire length. For production of the thick-wall plastic products it is necessary to use foaming agents during the plastic melt process. The foaming agent helps to create enough pressure within the plastic product to maintain the required shape and therefore each recycled plastic beam has three distinctive regions – a porous core in the center, a plastic shell and isolated locations with steel bars.

Testing

Although the material is clearly rate and time depended, as can be seen from rate dependent tensile tests shown in Fig. 1a, we concentrate here on the derivation of effective elastic properties only. To that end, we combine standard nanoindentation measurements with the Mori-Tanaka micromechanical model. To distinguish between the two regions the nanoindentation tests were performed both outside and inside the core at different temperatures. The influence of location and the effect of temperature on the measured elastic moduli are evident from Fig. 1b. These measurements clearly show and effect of foaming agent during the curing process on the resulting material stiffness.

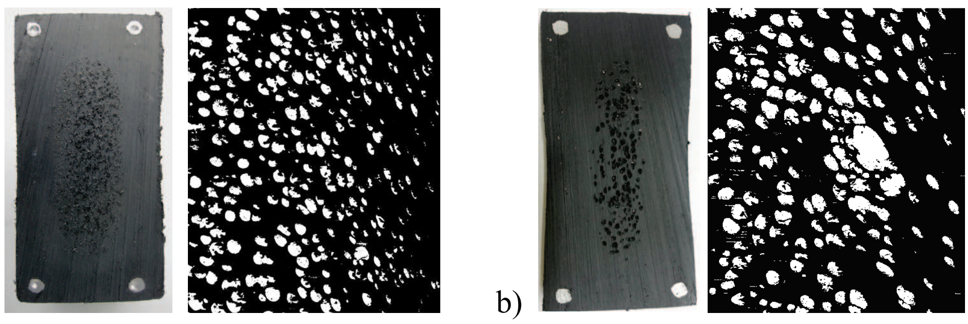


(a) (b)

Fig. 1: a) Tensile test stress-strain curve of recycled plastic under different strain rates, b) Evolution of Young's modulus measured by nanoindentation as a function of temperature

Image analysis and Mori-Tanaka Method

It has also been recognized that the production process results in variation of porous core along the beam axis as shown in Fig. 2. Clearly, the further from injection point the smaller the core gets but with increasing size of the pores. However, from the homogenization point of view, which draws up on the assumption of statistically uniform distribution of spherical pores, this plays no role. Here, the Mori-Tanaka micromechanical model [2] will be adopted assuming the volume fraction of pores is derived from 2D images of real material, Fig. 2(a,b). This is possible if accepting Delesse's law. This computational step is currently under investigation.



a) b)

Fig. 2: Porosity of the foamed core from different distances from the side of the injection of the beam a) 200 mm and b) 2800 mm.

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