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THIXOMOLDING OF MODERN CREEP-RESISTANT Mg-ALLOYS WITH PARTICLEAND FIBER REINFORCEMENTS FOR LIGHTWEIGHT APPLICATIONS

O. MYRONOVA[1], V. GORYANY[1], P. J. MAUK[1]

[1]*Institute of Applied Materials Technology (IAM), University of Duisburg-Essen, D-47048 Duisburg, Germany, myronova@ihg.uni-duisburg.de goryany@ihg.uni-duisburg.de, mauk@ihg.uni-duisburg.de*

ABSTRACT

Thixomolding® offers a variety of possibilities for the processing or implementation of innovative material concepts and, due to its specific process technology and engineering, meets all requirements that are imposed on a resource-saving and eco-friendly production process for magnesium components. Within the scope of a research project sponsored by the BMBF, modern non-reinforced and reinforced magnesium alloys with increased creep resistance were investigated. Given an adequately optimized process, the finished components generally featured total porosities of less than 2%.

The Thixomolding® process allowed carbon-fiber additions to be implemented, with a good fiber bonding between magnesium matrix and carbon fibers being achieved. It was equally possible to admix silicon particles to the feed stock and to produce Si-particle-reinforced components from these magnesium alloys.

Key words: Thixomolding®, magnesium alloys, creep-resistant

FUNDAMENTALS OF THE THIXOMOLDING® PROCESS

Thixomolding® is an innovative, fully-automatic and economical process belonging to the group of Thixoforming processes which are also called semi-solid processes. A special feature of this group of processes is the processing of metal alloys in semi-solid or part-liquid state, i.e. in the solidification interval (solidus-liquidus). In this temperature range, metals are suspensions which exhibit liquid and solid phase components and feature thixotropic behavior. The term thixotropy defines the reduction of viscosity responsive to an increasing duration of stressing. This process technology enables the low-cost production of castings with high quality and good mechanical properties.

Currently, this Thixo process is industrially employed mainly in Japan. The components produced are mostly used in the electronics industry (casings for mobile phones, notebook-computers, CD and DVD players, parts for digital photo cameras and digital video cameras, etc.).

Thixomolding® today mostly uses magnesium alloys, the starting material being chipped, cold magnesium granulate or alloy chips of defined size distribution which are produced by means of a special machining process. A conveyor system feeds these chips at room temperature to a rotating conveyor screw which takes the chips over and conveys them through a heating section under argon atmosphere right to the conveyor screw tip; this takes place at a conveyor screw speed of max. 210 RPM.

The conveyor screw is accommodated in a cylinder with external heating. Due to the fact that magnesium and its alloys easily oxidize in liquid state, it is of great importance that the cylinder be rinsed with argon during heating and during switchoff and/or cooling.

As the conveyor screw bore is specifically heated in several temperature zones that are distributed over the conveyor screw length, the magnesium compound undergoes uniform heating on its way to the conveyor screw tip due to continuous shearing.

The dendrites of the solidified portion of the magnesium compound are constantly sheared off and thus destroyed, whereby a viscous paste with solid, rounded off elements is produced.

In this semi-solid state, the alloy features thixotropic behavior. A fast, axial feed or forward motion (shot) of the conveyor screw results in that the semi-solidified melt is injected through the gate into a preheated metallic mold at high speed (between 10 and 100 m/s) and high pressure (~800 bar). Under the shearing action occurring during this procedure, the material becomes flowable so that, other than in conventional pressure casting/die-casting, a laminar filling of the cavity can be implemented.

When injection begins, there is a cold plug in the injection nozzle which serves as a seal to prevent the melt from flowing out in an uncontrolled manner or from oxidizing in the conveyor-screw pre-chamber. During injection, this plug is pressed out into a plug collector provided in the tool. Filling of the cavity completed, holding pressure is applied. Then, the alloy solidifies completely into a homogeneous, globular microstructure which is much finer-grained and, more importantly, denser than conventional die-cast material. In this way, markedly better material properties with lower material losses are achieved.

Rapid filling of the mold, a controlled flow behavior and precisely controlled temperature profiles of the mold are the challenges still to be mastered in order to achieve high density along with high quality. High density of the components allows a thermal treatment.

RESULTS OF THE INVESTIGATIONS AND TESTS

Within the scope of the research project, modern magnesium alloys based on the AM-alloy system with increased calcium contents (1.8 – 2.4 %) and the addition of further elements as well as alloys with additions of fine-grained and coarse-grained Si-particles and C-fibers were investigated. When exposed to higher temperatures, these alloys prove to be creep-resistant and also equivalent to corresponding aluminum alloys.

The components were manufactured with the Thixomolding® machine of University Duisburg-Essen (Fig. 1).

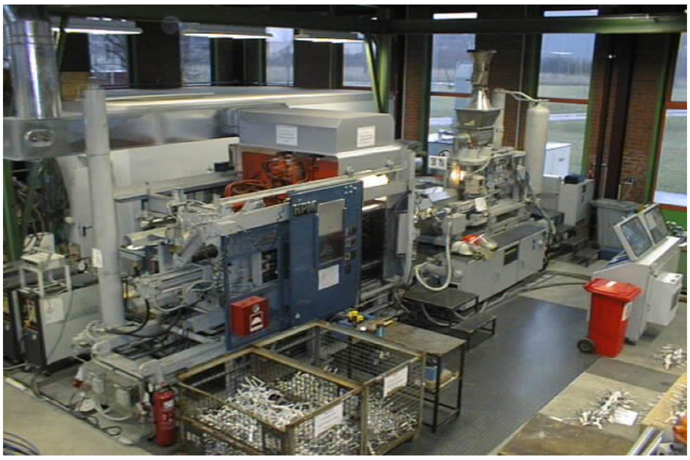
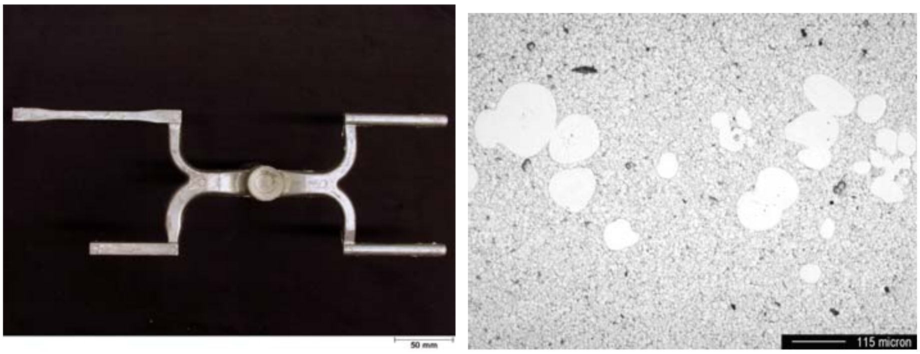


Fig. 1. Thixomolding® machine of University Duisburg-Essen

For Thixomolding® forming trials, a component with 4 specimens was selected, these specimen components being produced in series of up to 200 pieces. The round duct system leads via four gates to three tensile test pieces and one Charpy specimen that were tested in the following (Fig. 2a).



a *b*

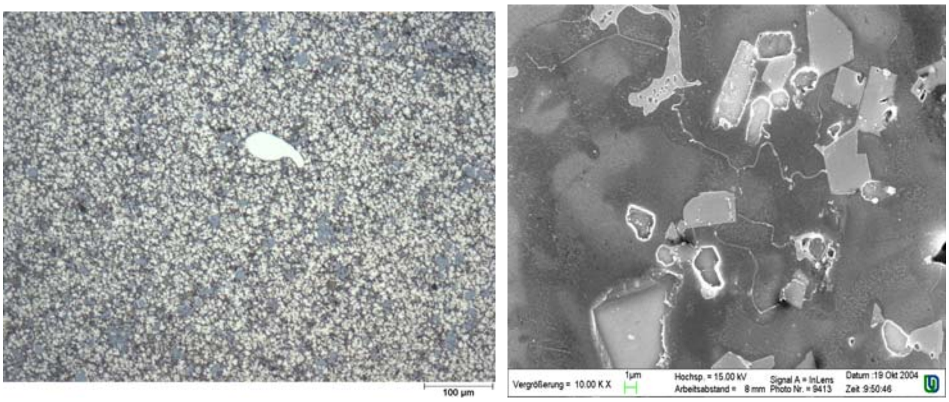
Fig. 2. Specimen component for ascertaining the mechanical properties (a); Thixomolding® microstructure of the alloys investigated (b). The black coloring indicates potential precipitations.

The volume porosity of the specimens tested was on a good level as compared to die-cast material. Typical specimens in part exhibited a porosity of clearly under 2%. Figure 2b depicts a typical Thixomolding® microstructure. Clearly recognizable is the bright, globular α-phase (solids share) which is surrounded by a very fine matrix. The solid content comes up to approx. 8%. The diameter of the α-globular grains ranges between 59 µm and 114 µm. The microstructure of the matrix conforms to the liquid phase during forming which results from a severe temperature drop and/or a high solidification speed. It contains the primary α-solid solutions, eutectic α-phase and eutectic brittle β-phase precipitating at the grain boundary.

Further investigations revealed that carbon fibers can be added in the Thixomolding® process, with a good fiber bonding between magnesium matrix and carbon fibers being attained. It was equally possible to admix silicon particles to the feed stock and to produce Si-particle-reinforced components from these magnesium alloys.

To produce the reinforced specimens, two different silicon powders were employed: 100-Mesh powder (grain size <150 µm) and powder containing a high share of fine-grained particles (grain size up to 20 µm).

The first trials with coarser powder (grain size <150 µm) showed that this powder is easy to meter with the small conveyor screw of the “fiber metering unit”. Figure 3 reflects some characteristics of the microstructure of these specimens made from the investigated alloy with coarse-grained Si-particles.



a *b*

Fig. 3. Investigated magnesium alloy + Si-particles (100-Mesh): a: micrograph solid content 0 - 0.55 %; b: REM-photo: round inclusions: Al-Ca-compounds; cube-shaped: Mg_2Si precipitations

Metallographic longitudinal and transverse sections reflect a fine-grained microstructure in the matrix and a uniform distribution of the particles with pronounced Mg_2Si precipitations (Fig. 3a, blue). Specimens with fine-grained Si-particles show no uniform scatter. The extent of porosity is greater than in the case of the alloy reinforced with coarse-grained Si-particles.

Following the silicon tests, the experiments on fiber reinforcement with carbon fibers were carried out; 8 - 10 % of c-fibers were added. The starting materials used for production of the composite material were Mg basic alloys and carbon fibers (C-fibers) of type C25M350. The composite materials employed were produced at a temperature of 600 °C. Fig. 5 reflects a uniform distribution of fibers, with the fiber volume share in the specimens (surface of transverse section) amounting to approx. 8 %.

Fig. 6 depicts REM-photos of this composite material. It is recognizable that the production parameters selected lead to a very good and complete bonding between fibers and matrix. There were no micro-cavities or pores detectable in the REM.

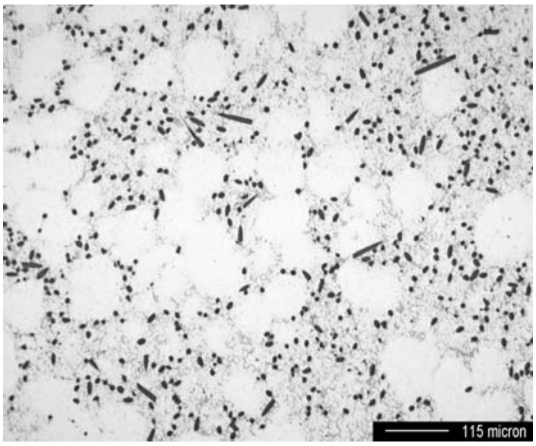


Fig. 5. Fiber distribution of Thixomolding® specimen

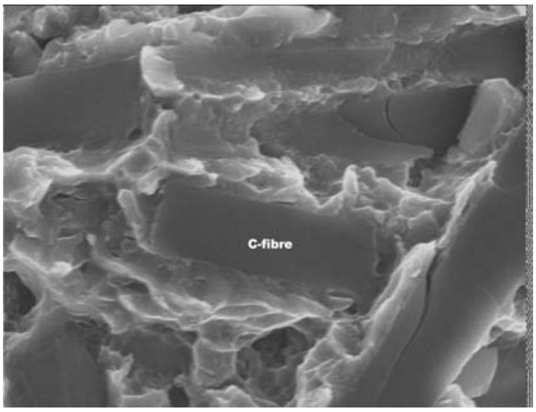


Fig. 6. Fracture surface of notched-bar impact test specimen from the Mg-matrix + Sigrafil C25M350. Fiber fragments (2300:1)

The proportional flat tensile specimens were used to ascertain the mechanical properties. The mechanical characteristic values of the test materials were determined by way of the uniaxial tensile test to DIN EN 10 002 („quasi-static“). The specimens in general show brittle fracture behavior. Higher tensile strength values of 284 N/mm^2 were attained with a fracture strain of 1.57 % at room temperature (Fig. 7). With 49 GPa on average, the modulus of elasticity also is lower than in the case of C-fiber reinforced specimens with a modulus of elasticity of 62 GPa.

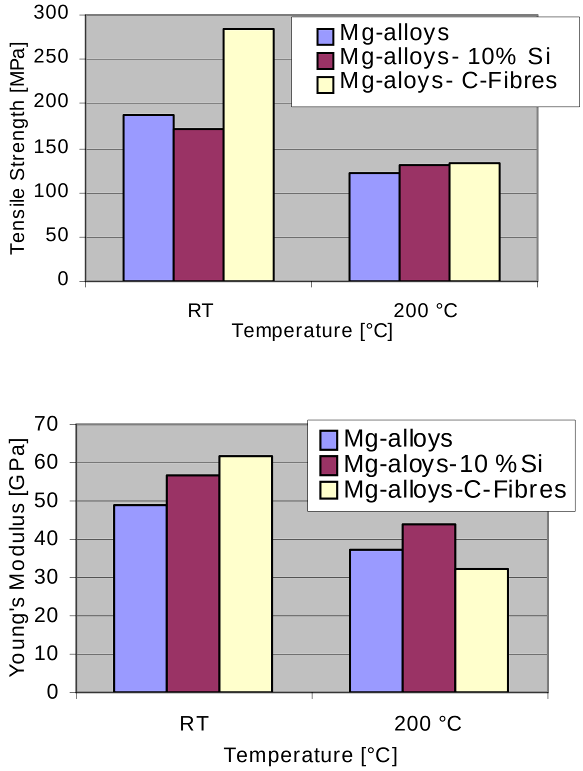


Fig. 7. Comparison of the mechanical properties of non-reinforced and reinforced magnesium alloys at room temperature and at 200°C test temperature

SUMMARY

The tests carried out produced components that were unobjectionable in terms of geometry and surface. The components exhibited a Thixo-microstructure with solid contents up to 10 % and, given an optimized Thixomolding® process, featured total porosities of approx. 2 %.

The tests in which Si was added and with carbon fibers of type Sigrafil 250 reveal that the Thixomolding® process basically permits a processing together with granulates. A suitable feeding system permits dry carbon fibers to be continuously added to the cylinder/conveyor screw unit via granulate infeed, and to be processed. Subject to adequate temperatures and injection pressures, the result is a good fiber bonding to the magnesium matrix in the component.

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