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Full Length Article

Modeling of transverse welds formation during liquid–solid extrusion directly following vacuum infiltration of magnesium matrix composite

Jian Liu [a], Lehua Qi [b,*], Haiyan Zhang [a], Heping Hou [a]

[a] Faculty of Printing, Packaging Engineering and Digital Media Technology, Xi'an University of Technology, Xi'an 710048, China
[b] School of Mechatronic Engineering, Northwestern Polytechnical University, Xi'an 710072, China

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Abstract

Liquid–solid extrusion directly following vacuum infiltration (LSEVI) is an infiltration–extrusion integrated forming technique, and transverse weld between upper residual magnesium alloy and magnesium matrix composites is a common internal defect, which can severely reduce the yield of composite products. To improve current understanding on the mechanism of transverse welding phenomenon, a thermo-mechanical numerical model of LSEVI for magnesium matrix composites was developed. The formation of transverse weld during extrusion was visualized using finite element simulation method, and the formation mechanism was discussed from the aspect of velocity field using a point tracking technique. The simulation results were verified by the experimental results in term of weld shape.

Keywords: Liquid–solid extrusion; Magnesium matrix composite; Transverse weld; Finite element simulation

1. Introduction

Magnesium matrix composite is a light-weight structural material with high performance, and has a wide application prospect in high-precision aerospace system, automotive industry and sports equipment due to their superior mechanical properties [1–3]. However, their applications are usually limited by poor formability and relatively high fabrication cost. The development of cost-effective fabrication techniques, therefore, is an essential element for expanding their applications. Liquid–solid extrusion following vacuum infiltration (LSEVI) is a special forming technique that integrates vacuum infiltration, squeeze casting and semi-solid extrusion [4]. It has a series of merits such as densification of matrix microstructure, uniform dispersion of reinforcement, perfect interfacial bonding, low deformation resistance in the liquid–solid state, and near-net forming.

Besides surface cracks and central cracks, inhomogeneous metal flow in liquid–solid extrusion process always leads to the formation of a cone-shaped transition region between the residual magnesium alloy and the composites (see Fig. 1). The interface (transverse weld) region is always porous due to the different flow velocities and solidification shrinkage levels between the composites and residual magnesium alloy. Hence, the transition region was usually cut out to obtain the pure composite section. However, it is hard to determine the position and length of weld seam by non-destructive method. In extrusion production, the transverse welding patterns and length are generally estimated by trial-and-error. By comparison, FEM technique is an effective and low-cost defect prediction method [5], which has been successfully applied on studies of transverse weld formation in hot extrusion process of aluminum alloy [6–8], trying to understand welding behavior concentrated upon the fact that die modification may influence the weld length and quality [9]. In this process, the new billet is welded onto the back surface of the old billet under extrusion force to maintain continuous production. However, the discontinuity caused by a weld interface in the microstructure of the extruded product can severely reduce the strength of the product, so it is important to minimize the transverse weld interface length while at the same time providing a high-quality weld.

For hot extrusion, the welding process is achieved in solid state between two same billets. The LSEVI is carried out in the semi-solid state containing a small amount of liquid phase, and the transverse weld is formed between composites and matrix

* Corresponding author. School of Mechatronic Engineering, Northwestern Polytechnical University, Xi'an 710072, China. Tel.: +8602988460447; fax: +86 29 88491982.

E-mail address: qilehua@nwpu.edu.cn (L. Qi).

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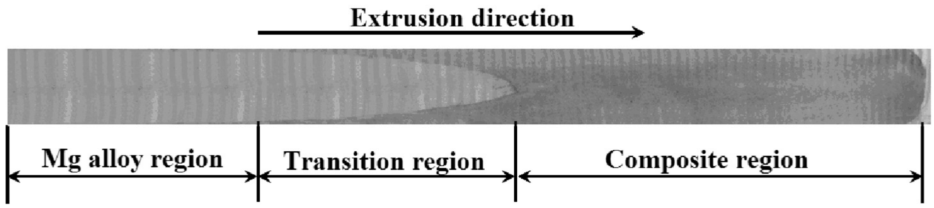

Fig. 1. Longitudinal section of composite rod fabricated by extrusion directly following vacuum infiltration technique.

metal. In addition, before extrusion, the composites and matrix metal bond together during solidification. At present, simulation studies about LSEVI are mainly concentrated on the load-stroke curve, temperature history, deformation pattern or macroscopic material flow, e.g. Qi et al. [10] used coupled thermal–mechanical rigid-viscoplastic FEM to analyze the solidification and subsequent extrusion process of composites, and gained the distribution of the stress, strain, flow velocity and temperature evolution in the extrusion process. Wang et al. [11] applied three-dimensional thermo-mechanical finite element method to reveal the formation mechanism of surface cracks based on temperature and velocity fields in the extrusion process. However, previous studies neglect the effect of residual magnesium alloy on the flow behavior of composites, and the transverse weld phenomenon has not been studied. In present paper, the thermo-mechanical finite element model of LSEVI for magnesium matrix composites reinforced by short carbon fibers was developed. The aim of this study is to provide an insight into the transverse weld phenomenon in LSEVI.

2. Modeling

LSEVI technique consists of four steps. First, magnesium alloy is melted in a sealed melting furnace, which is filled with argon to prevent oxidation, and carbon fiber preform is simultaneously preheated in extrusion die. Second, when the magnesium alloy and preform are preheated to the preset temperatures and held for a long time, the liquid meal is sucked into extrusion die via a stainless steel pipe which connects the melting unit and extrusion die, and then infiltrated into the preform immediately under gas pressure. Third, after infiltration, the magnesium alloy is forced to solidify under high squeezing pressure of punch. Finally, the infiltrated composites containing a small fraction of liquid phase are extruded out via the die exit when the container is cooled to the preset temperature. The schematic diagram of experimental setup is shown in Fig. 2.

In this study, the FE model of LSEVI consists of five objects to be simulated: billet (composite and magnesium alloy), punch, container, forming die, and plug rod, as schematically shown in Fig. 3. Due to the symmetry of billet, tools, boundary conditions and loads in whole forming process, half of the actual model was selected to establish the finite element model in order to reduce the computational workload and storage. To ensure computing convergence and computing precision, remeshing is necessary. The maximum interference depth was selected to start a remeshing procedure. If any portion of a master object (tools) penetrates into a slave object (billet) beyond a critical depth (it takes 0.25 mm in present model), remeshing will be triggered.

The thermo-mechanical behavior of the magnesium matrix composite at both the elevated temperature and in the semi-solid state was described using a modified viscoplastic law, which considers the effect of liquid phase [12],

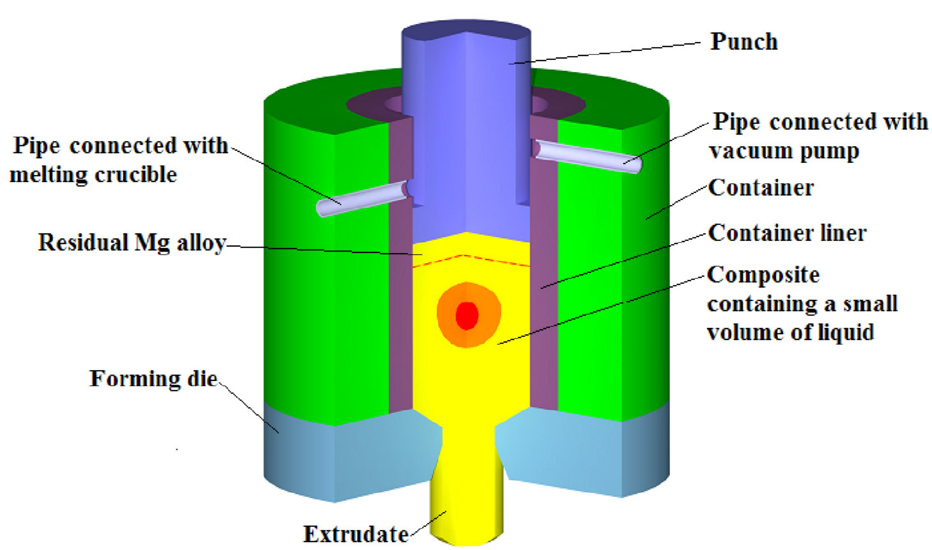

Fig. 2. Schematic diagram of liquid–solid extrusion following vacuum infiltration.