Damage of HVDC AlSiMgMn Alloys Using In-Situ Tensile with X-ray Tomography

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Abstract: AlSiMgMn alloys with different primary phases were prepared by high vacuum die-casting (HVDC) process. To evaluate the role of Fe-rich intermetallic characteristics on crack initiation, three-dimensional visualization of tensile damage process in these alloys was investigated by in-situ X-ray computed tomography (XCT). The results show that cracks in the alloy with primary α-Al were initiated at connection of shrinkage pore and damaged eutectic intermetallics while clustered primary intermetallics in the alloy with primary α-Fe led to crack formation.

Keywords: HVDC AlSiMgMn alloy; in-situ XCT; Fe-rich intermetallics; crack initiation

1 Introduction

In automotive industry, AlSiMgMn alloys are widely used in high vacuum die castings for their excellent castability and strength [1]. With increasing demands for economics and environmental sustainability, higher Fe content in AlSiMgMn alloys, which is detrimental to mechanical properties [2], has recently drawn much attention. With the change of Fe contents, Fe-rich intermetallics would precipitate in different solidifications, affecting mechanical behavior. Therefore, understanding the effects of different Fe-rich intermetallic characteristics and distributions on damage process is important for application of high Fe content alloys.

Benefiting from development of high-resolution X-ray computed tomography (CT) techniques, 3D in-situ analysis by X-rays implemented with mechanical test systems has become a powerful characterization option in materials science [3]. In this study, tensile damage processes of HVDC AlSiMgMn alloys with different primary phases were present, and the effects of eutectic and primary intermetallics on crack initiation were studied.

2 Experimental procedure

AlSi10MgMn alloys with different Mn contents were prepared by HVDC process (high vacuum of about 48 mbar), and their chemical compositions measured by ARL4460 are presented in Table 1. In our previous work [4], the Fe-rich intermetallics of alloy AE formed in eutectic while α-Fe phase first precipitated in alloy AP.

Table 1. Compositions of HVDC alloys (wt.%)

No.	Si	Mn	Fe	Mg	Al
AE	10.2	0.61	0.16	0.40	Bal.
AP	10.2	0.82	0.15	0.40	Bal.

The equipment of in-situ X-ray micro-CT experiments was ZEISS Xradia 520 versa coupled with tensile stage, as shown in Fig. 1a. The standard zone of specimens was 2 mm × 1 mm × 3.5 mm (Fig.1b) to obtain resolution of 2.531 μm for well reconstructions of Fe-rich intermetallics and microcracks. A constant displacement rate of 0.001 mm/min was applied to the tensile specimens and each alloy was tested three times.

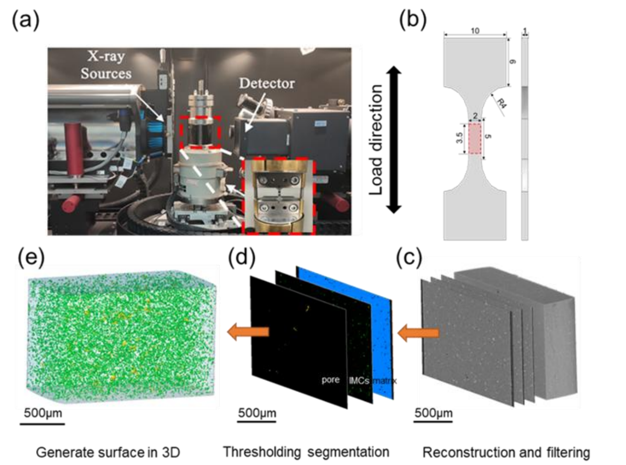

Fig. 1. (a) In-situ 3D tensile test set-up, (b) size of the specimens for tensile test, (c) original images volume rendering and slices, (d) segmentation of phases, and (e) 3D visualizations of intermetallics and microcracks.

3 Result and discussion

Tensile curves of alloys with different primary phases

The eutectic intermetallics in alloy AE had polyhedron shape and were with dispersed distribution, while lots of hexahedron or octagonal dendrite shapes primary intermetallics in alloy AP clustered distributed.

In Fig. 2, each specimen has five scanning points (indicated by red dots), in which point A represents the time before loading. Point B represents the time when the microcracks were first observed. It can be seen that damage occurred at higher strain in alloy AE. Point D represents the time start of crack propagation, which is determined by a sudden drop in force. Point E represents the time of specimen complete fracture. Comparing stress-strain curve of the alloys, lower elongation in alloy AP indicated that clustered intermetallics would be detrimental to ductile.

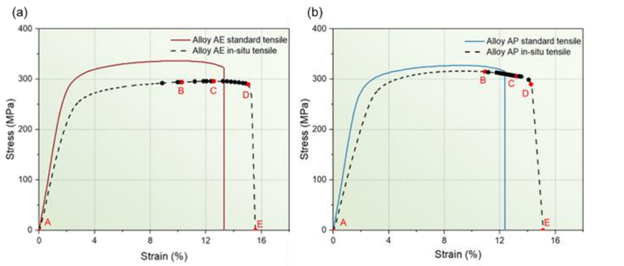

Fig. 2. Stress-strain curves in standard tensile and in-situ tensile of alloys AE (a) and AP (b).

Crack initiation in alloy with primary α -Al

Fig. 3a shows the 3D morphologies of shrinkage pores and cracks in alloy AE. It can be seen that pores in the alloy were isolated in distribution. They enlarged under the load and didn't connect before fracture. As shown in Fig. 3b, six polyhedral intermetallics were around the shrinkage pore, which is near the specimen surface. With the strain increased, the shrinkage pore further enlarged, and many intermetallics were damaged at high strain. The connection of shrinkage pore and microcracks resulted in the formation of crack in alloy AE.

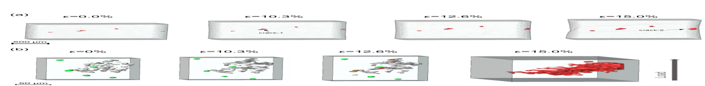

Fig. 3. 3D morphologies of shrinkage pores and cracks in the tensile process (a) and crack initiation (crack-2) in alloy AE (cracks indicated by red, intermetallics indicated by green and shrikage pores indicated by grey).

Crack initiation in alloy with primary α -Fe

Different in alloy AP, with the strain increased, new cracks formed and connected, resulting in a significant crack propagation, as shown in Fig. 4a. From Fig. 4b and c, clustered primary intermetallics fractured and formed larger microcracks at low strain. These microcracks connected with each other, becoming the crack initiation sites.

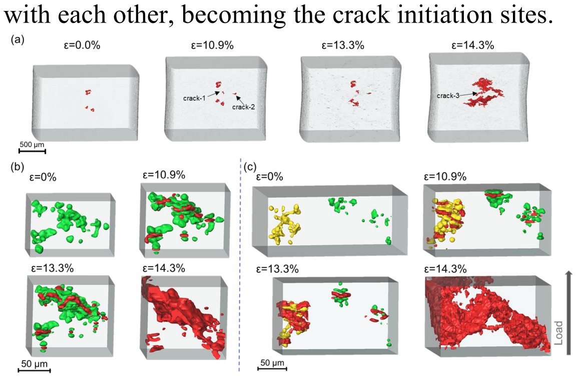

Fig. 4. 3D morphologies of cracks in the tensile process (a) and crack initiation in alloy AP: (b) crack-1, (c) crack-3 (cracks indicated by red and clustered intermetallics indicated by green or yellow).

4 Conclusion

3D in-situ tensile of HVDC AlSiMgMn alloys was conducted and the initiation of cracks was investigated. For alloy with primary α-Al, eutectic Fe-rich intermetallics were damaged at high strain, and the crack was initiated at the connection of shrinkage pore and microcracks. For alloy with primary α-Fe, clustered primary intermetallics fractured at low strain, and cracks initiated at the connection of microcracks.

Acknowledgments

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