Proceedings of the 72nd World Foundry Congress
21-25th May 2016, Nagoya, Japan

A Chemical Pre-treatment Process for Adhesive Bonding of High-Pressure Die Cast Aluminum Alloys

Jianmin Shi, Torsten Schuchardt, Helge Pries, Elisabeth Stammen and Klaus Dilger
Institute of Joining and Welding, Technische Universität Braunschweig,
Langer Kamp 8, 38106 Braunschweig, Germany

High-pressure die cast (HPDC) aluminum components are widely used in the assembly of vehicle structures for weight-reduction. Joining of HPDC aluminum castings with other structural parts using adhesives is still challenging due to the inherent contamination of casting surfaces by die lubricants. In this paper we report on the development of a universal chemical pre-treatment process for the reliable fabrication of adhesively bonded HPDC aluminum joints. The effectiveness of the three-step chemical pre-treatment process, consisting in degreasing in alkaline solutions, deoxidation in fluoride-containing sulfuric acid solutions and dipping in hexaflurotitanic acid solutions, was verified by the evaluation of the durability of epoxy-bonded HPDC plates after aging in 5 wt % NaCl solution at 70 °C.

Keywords: *High-pressure die casting, aluminum alloys, surface pretreatment, adhesive bonding, durability.*

1. Introduction

High-pressure die casting (HPDC) of Al alloys is an attractive manufacturing process for light-weight structural parts in the automobile industry. Integration of Al die castings into hybrid vehicle-structures using adhesives is still challenging due to the inherent contamination of the casting surfaces by residual lubricants and the inhomogeneous distributions of alloying elements. Our previous work on the adhesion properties of HPDC Al alloys showed that the adhesive bonding property of an HPDC Al casting varies significantly at different locations on the casting surface [1,2]. Based on the surface chemical analysis and the evaluation of bonding strength, we have developed a chemical process for the pre-treatment of HPDC Al alloys to fabricate adhesively bonded structures using HPDC Al components. This 3-step process was optimized with respect to chemicals used in the second and third steps [1,2]. In this paper we report on the applicability of the optimized pre-treatment process to other HPDC alloys cast with different die lubricants.

2. Materials and experimental methods

Two Al alloys, EN AC-AlSi9Cu3(Fe) and EN AC AlSi10MnMg were fabricated into plates (260×150×4 mm^3) using HPDC machine with polysiloxane-based emulsions as die lubricants.

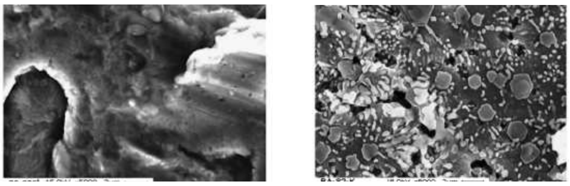
The chemicals used for the pre-treatment of HPDC Al alloys were selected from commercially available industrial products based on their main ingredients. Surface pretreatment was carried by degreasing in NaOH solutions followed by deoxidation in F^--containing H_2SO_4 solutions and deposition of Ti-based conversion coatings. The surface morphology and chemical compositions before and after chemical treatment were examined by using scanning electron microcopy (SEM) and X-ray photoelectron spectroscopy (XPS), respectively.

A structural adhesive based on epoxy was used to fabricate wedge specimens according to the German standard, DIN 65448 and cured at 180°C for 30 min. The initial crack length and crack extension were measured before and after aging at 70°C in 5wt% NaCl solutions. Finally, the wedge specimens were opened for examination of fracture surfaces.

3. Results and discussion

3.1 Changes in surface morphology and chemical compositions after chemical treatment

The change in surface morphology after the chemical treatment of HPDC AlSi10MnMg is shown in Fig. 1. The relatively featureless surface morphology of the as-cast surface changed into a rough pattern with exposure of intermetallic phases and Si particles and formation of pitting holes at the grain boundaries, due to etching effects of chemicals used. The surface chemical composition was characterized using XPS survey scans and high-resolution spectra of Si2p, respectively, before and after chemical treatment.



(a) (b)

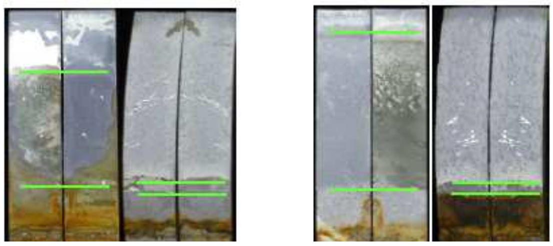
Fig. 1 SEM micrographs of the surface of HPDC AlSi10MnMg plates: (a) as-cast and (b) after chemical treatment.

After chemical treatment, the concentration of C-containing species decreased from about 65 at% on the as-cast surface to about 40 at% on chemically treated ones and is accompanied by an increase in atomic concentration of oxygen and aluminum. The deposition of Ti-oxide conversion coating was confirmed by the appearance of Ti signals (about 0.5 at%) in the survey scan of the chemically treated surface. On one hand, the decrease in Si concentration after chemical treatment is another indicator for removing residual lubricants. On the other hand, the high-resolution Si2p spectrum of the as-cast surface is dominated by organic Si species resulting from the residual lubricants while that of chemically treated surfaces is dominated by inorganic Si, i.e., Si and SiO_2. The results of surface characterization confirmed the effectiveness of chemical treatment for the removal of residual lubricants and the deposition of corrosion-resistant Ti-oxide coatings.

3.2 Initial bonding properties and the durability of adhesive Joints

The evaluation of adhesion properties using wedge specimens show that longer initial crack length and crack extension were observed for the as-cast state than for the chemically treated specimen. It is also noticed that the alloying elements in HPDC alloys influence only the durability of adhesive joints fabricated in the as-cast state. This result suggested that the chemical pretreatment process is suitable for the pre-treatment of different HPDC alloys, thus being a universal process for adhesive bonding of HPDC Al alloys.

Representative fracture surfaces after opening the wedge specimen fabricated with and without chemical treatment are shown in Fig. 2 for the two HPDC alloys. The fracture surfaces of adhesive joints in the as-cast state exhibit a failure mode dominated by adhesive failure while those of chemically treated specimens show a cohesive failure mode for both HPDC alloys. From the surface characterization and the comparison of bonding properties of the as-cast and the chemically pretreated specimens, one can conclude that the developed chemical pre-treatment process can substantially improve the durability of adhesive joints involving HPDC Al alloys and is applicable to various HPDC Al alloys for adhesive bonding.



as-cast chem. as-cast chem.

(a) (b)

Fig. 2 Fracture surfaces of wedge specimens fabricated in the as-cast and chemically treated (chem.) states of (a) HPDC AlSi10MnMg and (b) HPDC AlSi9Cu3(Fe) alloys. The crack extension is marked by the green lines in each photograph.

4. Conclusions

A chemical pretreatment process for the reliable fabrication of adhesive joints involving HPDC Al alloys is demonstrated in this paper. The chemical pre-treatment process consists in degreasing in NaOH solutions, deoxidation in fluoride-containing sulfuric acid solutions and deposition of Ti-oxide coatings. The effectiveness of the chemical treatment process was verified by surface characterization and durability tests of adhesive joints. The optimized chemical process is found to be a universal pre-treatment process for HPDC Al alloys of various chemical compositions and cast with different die lubricants.

Acknowledgements

Financial support from the German Ministry of Economics and Energy (BMWi) through Industrial Collective Research (IGF) is greatly acknowledged.

References

[1] J. Shi, H. Pries, K. Dilger, M. Martin and F. Walther: Surface chemical inhomogeneity of high-pressure die cast Al-Si alloys and its effects on corrosion behaviors and adhesive bonding capabilities, in Proc. of the 71st World Foundry Congress. 2014, Bilbao, Spain.

[2] J. Shi, H. Pries, E. Stammen and K. Dilger: Int. J. Adhes. Adhes. 61 (2015) 112-121.