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Superhydrophobic Aluminium Surface Obtained via Laser Structuring and Stearic Acid Grafting with Corrosion Protection and Anti-Icing Abilities

Nina Kovač[1,2], Matic Može[3], Barbara Kapun[1], Iztok Golobič[3], Ingrid Milošev[1], Peter Rodič[1]

[1] Jožef Stefan Institute, Department of Physical and Organic Chemistry, Jamova c. 39, 1000 Ljubljana, Slovenia
[2] Jožef Stefan International Postgraduate School, 1000 Ljubljana, Jamova c. 39, Slovenia
[3] University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva c. 6, 1000 Ljubljana, Slovenia

INTRODUCTION & AIM

Aluminium and its alloys are widely used in the automotive, aerospace, and marine industries due to their excellent mechanical properties and corrosion resistance. However, their susceptibility to corrosion in chloride-rich environments necessitates effective protection strategies.

One promising approach is the development of superhydrophobic surfaces, which exhibit extreme water repellency (contact angle >150°) by combining hierarchical surface structures with low-surface-energy materials.[1,2]

This study aimed to enhance corrosion resistance and anti-icing properties by integrating laser surface structuring with stearic acid grafting.

MATERIALS & METHODS

The die-cast aluminium alloy AlSi7Mg0.3/EN AC-42,100 (A356) was distributed by manufacturer Talum d.d., Slovenia, Europe. The structured modified surface was 2.5 cm × 2.5 cm. The preparation of the superhydrophobic aluminium surface consists of a two-step process,[3] as illustrated in Figure 1.

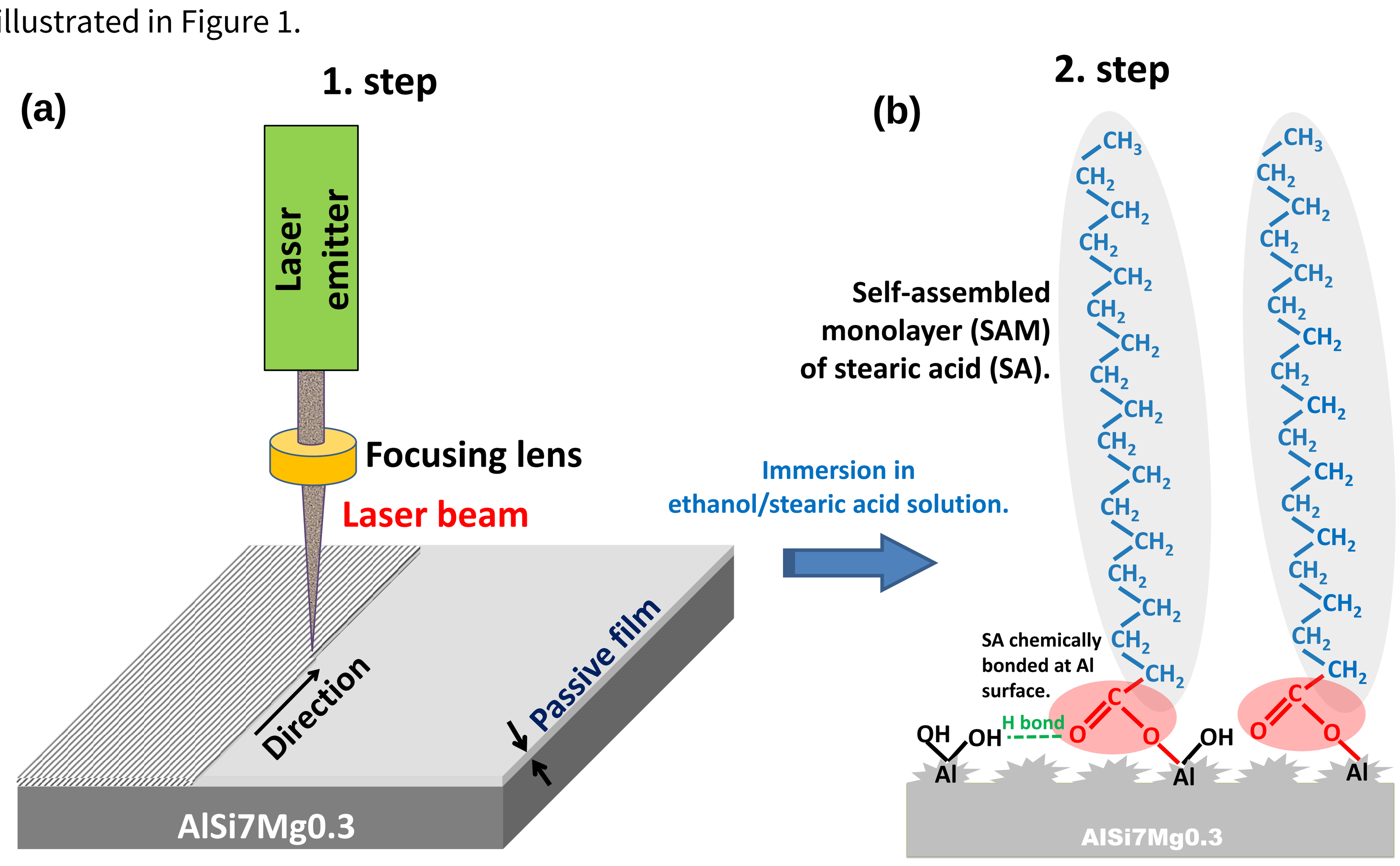

Figure 1. The scheme presents the two-step process to create a (super)hydrophobic aluminium surface. The first step consists of laser structuring of the aluminium surface (a) and (b), followed by grafting with stearic acid (SA).

A selected laser structuring was performed using a nanosecond pulsed fibre laser system (FL-mark C equipped with a MOPA source from JPT Opto-electronics "M7 30 W"). The scan rate was set at 110 mm/s, with a pulse frequency of 110 kHz and a pulse duration of 45 ns and a scanning line spacings 70 µm.

The obtained rough surface was then grafted with a stearic acid coating by immersion in 0.1 M SA/ethanol solution for 1 hour.

Surface morphology, roughness and wettability, were analyzed using scanning electron microscopy (FEI Helios NanoLab 600 Dual-beam), a contact profilometer (Bruker DektakXT), and a goniometer (Krüss FM40 EasyDrop). Corrosion resistance was evaluated via electrochemical testing using a potentiostat/galvanostat Autolab PGSTAT M204 (Metrohm Autolab, Utrecht, Netherlands) in 0.1 M NaCl.

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RESULTS & DISCUSSION

Secondary electron SEM images of the laser-structured surface reveal numerous large and deep valleys (Fig. 2), along with the development of micro- and nano-structured surface features. The nanostructure becomes more apparent at higher magnification (Zoom in), indicating the potential for air entrapment within the micro- and nano-scale features. The EDS confirmed great amount of Al and O related to surface passivation. Si and Mg are related to aluminium alloy intermetallics.

	At%
Al	61.0
O	30.7
N	4.0
Si	3.8
Mg	0.5

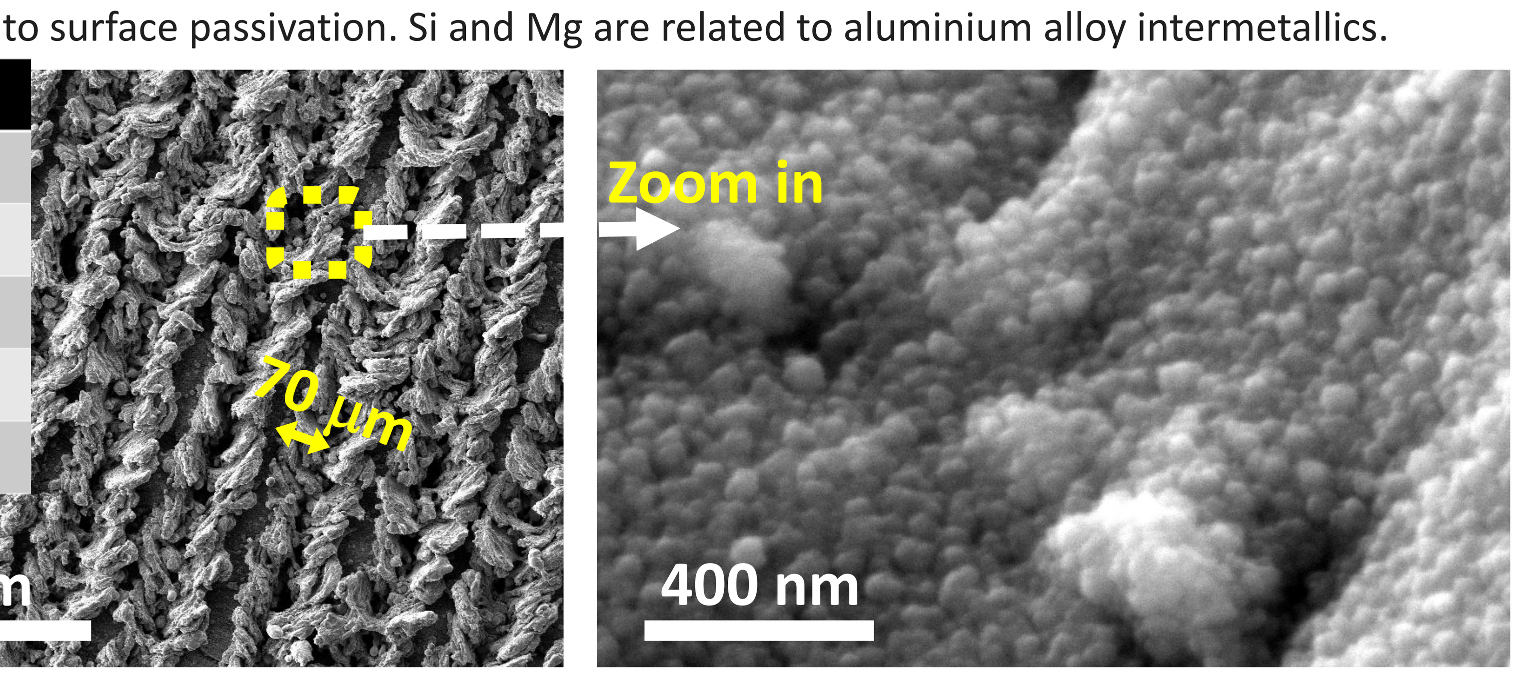

Figure 2. Secondary electron SEM images of laser-structured surfaces prepared using laser scanning line spacing modified with stearic acid. EDS spectrum and surface composition are given in atomic percentages (at. %); carbon is excluded.

The untreated (REF) surface of AlSi7Mg0.3 exhibits inherent hydrophilicity due to the natural oxide layer (Al_2O_3). Laser structuring enhances the surface wettability, transitioning the surface to superhydrophilic behaviour (the water droplets wet the surface completely). Significant improvements in hydrophobicity are observed on laser-structured surface modification with SA, the contact angle surpasses the superhydrophobic threshold (>150°) as shown in Figure 3.

Figure 3. Wettability of the (a) REF surface, (b) laser-structured alloy and (c) grafted with stearic acid.

The observed decrease in corrosion resistance of LS compared to REF is likely due to aggressive chloride ions, which penetrate through the freshly formed passive layer after laser-structuring. Surface modification with SA significantly reduces i_{corr} by more than three orders of magnitude. The improvement in corrosion properties is due to the superhydrophobic nature of the LS+SA surface, as shown in Figure 4.

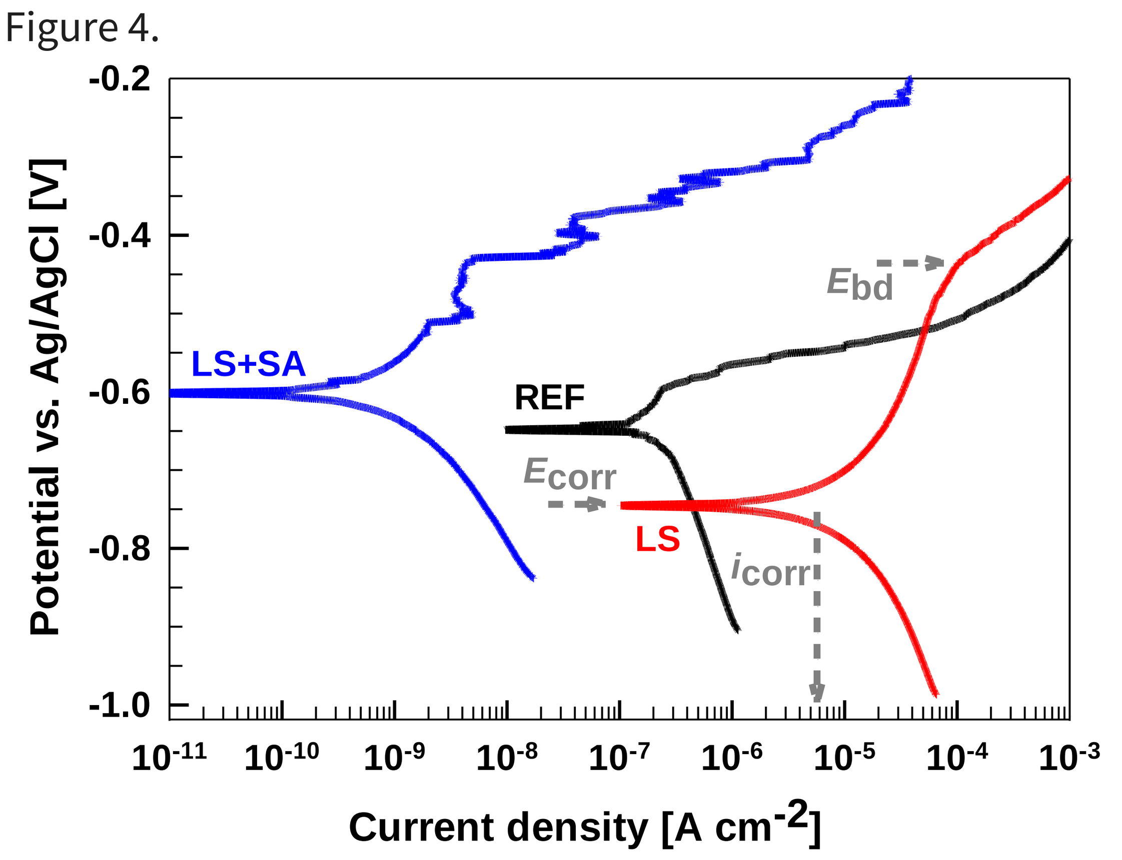

Figure 4. Potentiodynamic polarisation measurements after one hour of immersion in 0.1 M NaCl solution for laser-structured AlSi7Mg0.3 samples prepared without and with modification of stearic acid.

CONCLUSIONS & FUTURE WORK

A superhydrophobic aluminium surface was successfully developed using laser-structuring and surface modification. The main findings are as follows:

- Laser structuring proved to be an effective and rapid technique for inducing hierarchical micro- and nanostructures on the cast aluminium alloy AlSi7Mg0.3.
- SEM analysis confirmed the presence of a well-defined hierarchical surface morphology.
- Potentiodynamic polarisation testing in 0.1 M NaCl solution revealed poor corrosion resistance of the laser-structured surface alone, but a notable enhancement in corrosion protection was observed following stearic acid grafting.

This adaptable method holds promise for application to other aluminium alloys in future studies, offering potential for varios industrial uses.