Lasers in Manufacturing Conference 2015

Use of High-Energy Laser Radiation for Surface Preparation of Magnesium for Adhesive Applications

N. Schneider[a,*], C. Wrobel[b], J. Holtmannspoetter[a], G. Loewisch[b]

[a]*Bundeswehr Research Institute for Materials, Fuels and Lubricants; Institutsweg 1, 85435 Erding, Germany*
[b]*Bundeswehr University, Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany*

Abstract

This paper is intended to demonstrate how the parameters for the surface preparation of magnesium alloys for adhesive bonding can be optimized. The effects of different laser parameters are analyzed using a combination of advanced sample preparation and ultra-high resolution scanning electron microscopy on the nanoscale level and a specific combination of mechanical tests on the macroscopic level. This data allows a discussion of the physical principles and the key parameters influencing the interaction of laser radiation with the magnesium surface.

Keywords: Micro Processing, Surface Functionalization

1. Introduction

Magnesium alloys are very versatile materials. Their high specific strength, combined with easy machining, suggest their application in any kind of lightweight structure. For the use of magnesium in multi-material construction methods, i.e. in combination with other materials, efficient joining technologies need to be developed.

Adhesive bonding is a process that is perfectly suited to connect different materials. Due to its position in the electrochemical series (standard potential: -2,362 V), magnesium is a base metal. This means that magnesium corroded very easily, especially in contact with other metals. In this respect the surface pretreatment and corrosion protection are major challenges in order to ensure the durability of the bonding.

* Corresponding author. Tel.: +49-8122-9590-3616; fax: +49-8122-9590-3602
E-mail address: norbert2schneider@bundeswehr.org

The functionalization of magnesium surfaces by high-energy laser radiation is a promising and cost saving alternative to mechanical (e. g. grinding) or chemical pretreatment methods like pickling or anodizing.

2. Experiments

For these experiments a Nd:YAG-Laser was used. It has a wavelength of 1.064 nm, a mean laser power of 100 W and the pulse frequency could be varied between 1 Hz and 50 kHz. Because of the use of pulsed laser radiation with pulse duration of 70 ns, the thermal input is localized directly at the surface. The focusing of the short laser pulses to a footprint of approximately 200 µm results in very high energy densities, so that the magnesium surface is remelted or sublimated within a few microseconds. At the same time, plasma is generated, which contains the major part of the thermal energy and removes this energy from the surface. Therefore, only very little heat is transferred into the bulk material. This way a change in microstructure could be avoided and it was also possible to process very thin magnesium-substrates and pretreat them for adhesive bonding.

For a first assessment of different pretreatment methods like SACO blasting, pickling and some initial laser parameters, T-peel-tests according to DIN EN ISO 11339 were performed. The optimization of the laser parameters was done by means of roller peel tests according to DIN EN 1464. For the optical inspection of the surfaces a field emission scanning electron microscope (FE-SEM) was used. The cross section samples were prepared with a cross section polisher (CSP) by means of a defocussed argon ion beam.

The experiments were performed with the film adhesive FM® 73, a fracture tough adhesive used in bonded repairs. Its performance is well known from a lot of other experiments in the past, so that the influence of the surface preparation could be clearly determined. Some of the samples were cured in an autoclave process, the others were cured by means of a Hot Bonder.

3. Results

The laser treatment with a Nd:YAG-Laser generates an oxide layer on the surface (see Fig. 1), which is essential for the strength of the bonding.

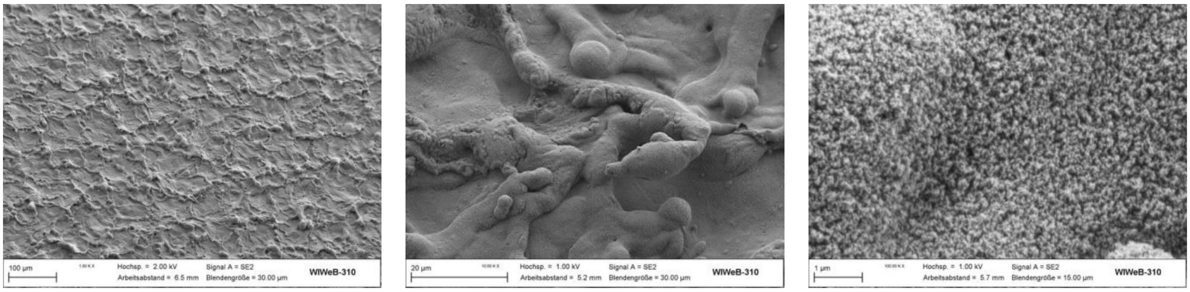

Fig. 1: FE-SEM pictures of the surface of a AZ31-alloy after treatment with a Nd:YAG-Laser (magnification 1.000 x , 10.000 x and 100.000 x)

To get a first impression of the performance of the laser surface preparation compared to conventional pretreatments like SACO-blasting or pickling, some T-Peel-tests according to DIN EN ISO 11339 were performed. The results of these tests are shown in Fig. 2. The excellent suitability of the laser pretreatment is already visible in these simple tests.

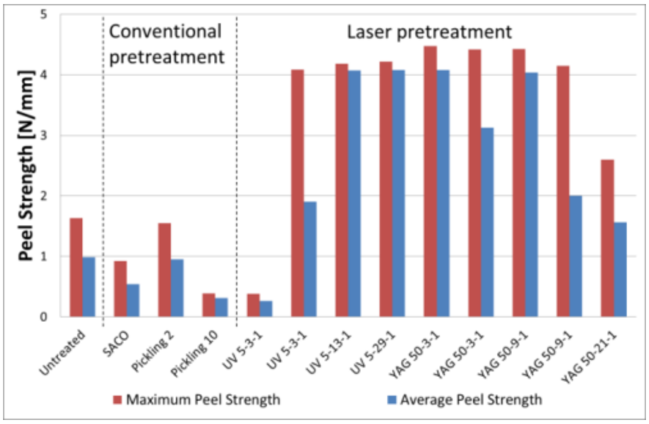

Fig. 2: Peel strength (T-Peel-Test) of bonded AZ 31 magnesium-sheets with conventional pretreatment or laser pretreatment

To optimize these first laser parameters, roller peel tests according to DIN EN 1464 were performed and subsequently cross sections of these specimens were investigated with the high resolution FE-SEM (see Fig. 3 (a) and (b)).

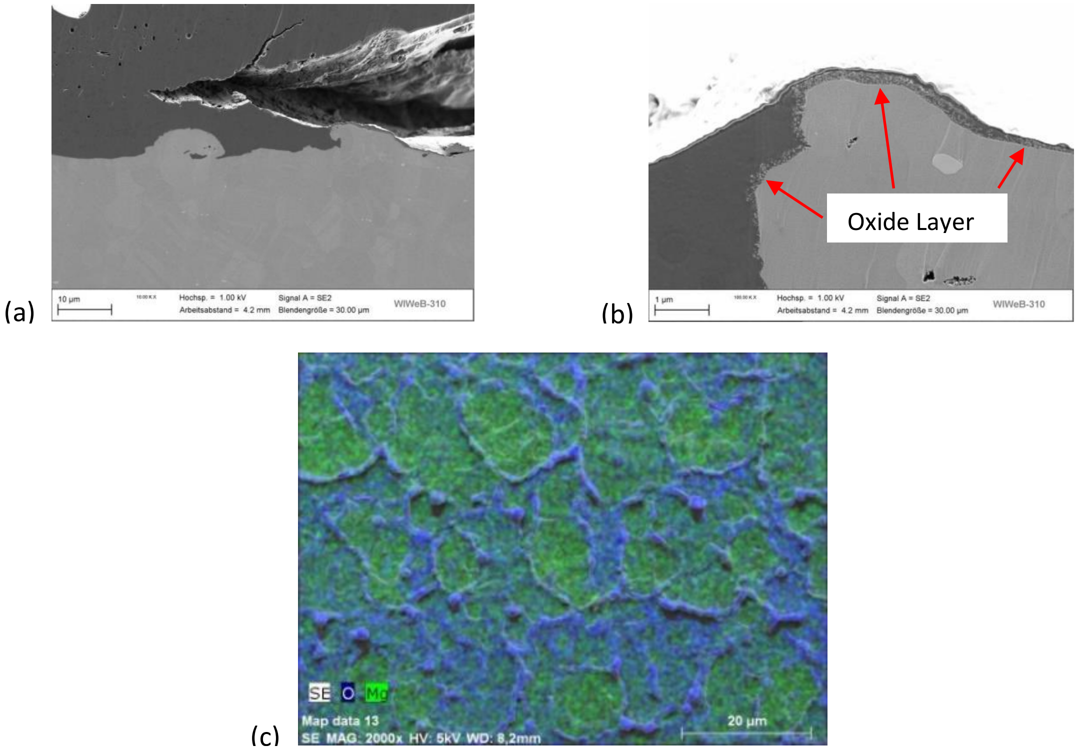

Fig. 3: (a) and (b) High resolution FE-SEM images of cross sections of destructive tested bonded AZ31specimen; (c) EDX mapping of a laser treated magnesium surface with the distribution of the elements oxygen (blue) and magnesium (green)

The correlation of the adhesion to the distribution of the oxide is of particular interest. The distribution of the elements oxygen and magnesium is displayed in Fig. 3 (c). The oxide is located mostly on the edges of the depressions created by single laser pulses whereas inside the depressions there is little or no oxide detectable. To achieve a more homogenous oxide layer, the forward speed of the laser beam was halved to realize a bigger overlap of the single laser pulses. So the overlap of the single laser pulses was raised from approximately 50 up to 75 % overlap. The results of this improvement are displayed in Fig. 4. The use of an additional primer BR 127 CF did not further enhance the adhesion in the unaged specimens. The influence of the curing process either with a hot bonder or an autoclave is relatively small, only the average peel strength for the specimens cured in the autoclave shows slightly higher values.

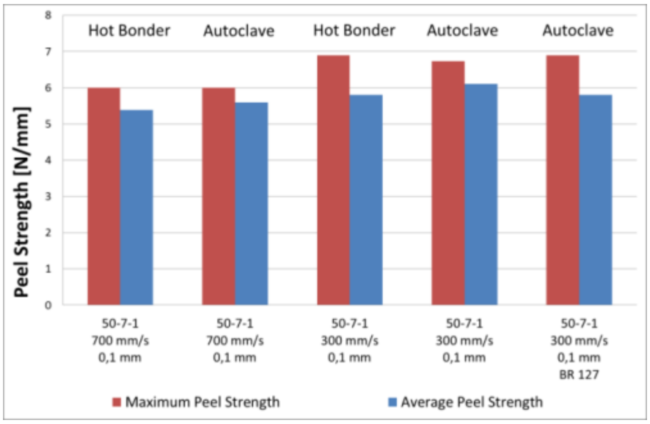

Fig. 4: Improvement of the peel strength through variation of the overlap of the single laser pulses

4. Conclusion

It was shown that pulsed high energy laser radiation is a very promising alternative for the pretreatment of thin magnesium sheets compared to conventional methods like SACO-blasting or pickling. The laser pretreatment generates a thin oxide layer on the surface of the magnesium, which results in a very good interleaving of the adhesive with the surface. All parameter have to be optimized regarding the building of a homogenous oxide layer. The most important parameter is the forward speed of the guided laser beam. The halving of the forward speed increases the peel strength significantly.

By combining of destructive tests, innovative preparation methods and FE scanning microscopy (especially fracture analysis of cross sections), the surface pretreatment could be optimized. As a result, high strength of adhesive bonding of magnesium-alloys could be achieved. This fast physical process fulfils all legal requirements concerning environmental protection and occupational safety and also has low operating costs.