DECHEMA Karl-Winnacker-Institut

Corrosion

Microstructure oriented fatigue and damage analysis of friction stir welding of Al alloys considering corrosive effects

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Introduction

Friction stir welding (FSW) of aluminium has become an increasingly sophisticated technology with numerous commercial applications [1]. A process developed by TWI, Cambridge, FSW involves the joining of metals without fusion or filler materials. It is mostly used for the joining of structural components made of aluminium and its alloys. The process is most suitable for components which are flat and long (plates and sheet) but can be adapted for pipes, hollow sections and positional welding. The welds are created by the combined action of frictional heating and mechanical deformation due to a rotating tool [2]. The maximum temperature reached is in the order of 0.8 of the melting temperature [3]. Due to the friction stir welding process, there are different micro-zones which can be identified as the parental material (AGW), advancing and trailing heat affected zone (HAZ), the thermo-mechanically affected side of the weldments (TMAZ) and the nugget [4]. The different zones of the weldment may have different susceptibilities to corrosion. Localized corrosion is strongly influenced by the presence of second phase particles (Mg_2Si-Phase and Al-Cr-Mn-Fe-Particles), whose size and distribution in the alloy are dependent upon the weld schedule [5]. Therefore it is important to make a complete study of the corrosion properties of various friction stir weldings of aluminium alloys depending on their welding parameters.

In the course of this project a comprehensive mechanism and durability oriented program was examined concerning the coherences between microstructure and material corrosion fatigue properties. The aim is to fulfil requirements for a potential application of the FSW process to interconnect thin metallic plates or slices of different materials and to develop and provide a criterion and failure catalogue based on the achieved experimental results for a future FSW user.

Experimental

Electrochemical measurements such as open circuit potential (OCP) measurement, potentiodynamic polarization and microstructurally resolved Scanning Kelvin probe measurements of the FSW specimen were performed to investigate the corrosion properties. An electrochemical cell was filled with NaCl solution and connected to a VoltaLab 80 PGZ 402 Potentiostat from Radiometer. It also included a platinum counter electrode and a saturated calomel (Hg_2Cl_2) reference electrode (0.244 V vs. SHE at 25 °C). The applied potential scan rate in potentiodynamic polarization was 0.1mV/s.

The salt spray test was performed according ISO 9227 inside a 400 liter temperature-controlled chamber (Erichsen Testing Equipment, Corrtherm 610), spraying a fine salt solution fog (5% NaCl) onto the specimen being tested. The FSW-Al/Al and FSW-Al/steel weldments were inserted into the chamber at an angle of 65° and maintained at a temperature of 35 °C for about 172 hours. The assessment of the corrosion susceptibility of the FSW weldments was done every 24 hours.

The microstructure oriented space resolved corrosion studies were performed by SKP_KM (Scanning Kelvin Probe with height Control) and Scanning Kelvin Probe Force Microscopy (SKPFM) . The Scanning Kelvin probe (SKP) needle is made of a Cr-Ni-alloy of 100 µm in diameter. The KP needle vibrates with an amplitude of 1 to 30 µm and a frequency of 1 KHz with a 1V *B*acking potential at 10 Hz frequency. The Scanning Kelvin Probe Force Microscopy (SKPFM) is based on a Multimode V AFM from Veeco.

Results of the microstructural resolved corrosion measurements on FSW Al/Al-5754 overlap weldment

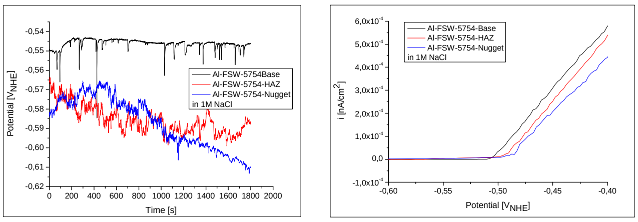

Fig.1: Representative examples of OCP (potential vs. time) and the potentiodynamic polarization (current density vs. potential) of the FSW Al/Al-5754 overlap weldment in 1M NaCl solution. The results of the electrochemical measurements demonstrate that the OCP of the weldment depends on alloy composition, electrolyte concentration and welding process. The oxide breakdown potential is also dependent on the electrolyte concentration and slightly on the alloy composition but rather not on the welding process.

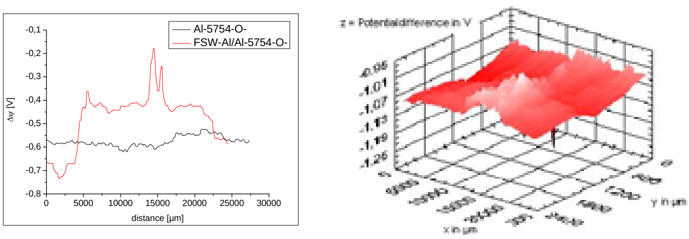

Fig.3: Representative examples of micro structural resolved Scanning Kelvin probe line scans of the Parental and FSW AlAl-5754-0 overlap weldment in ambient atmosphere. Second plot depicts a Kelvin probe surface scan of the weldment. The results of the Scanning Kelvin probe technique demonstrate that the Volta potential of the working material depends on the welding process and the different FSW zones.

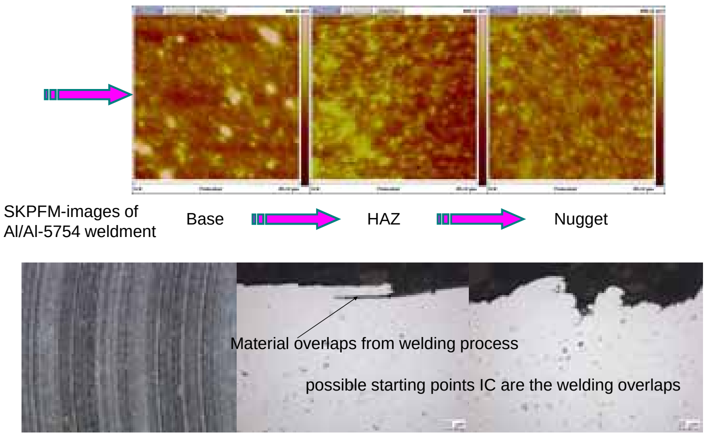

Fig. 2: Representative examples of Scanning Kelvin Probe Force Microscopy (SKPFM) and optical microscopy (surface and cross sectional) images after ASTM G110-92 for the clarification of intergranular corrosion of the Al/Al-5754 weldment. The specimen Al/Al-5754 show no intergranular corrosion whatsoever. Nevertheless, there is a kind of pitting corrosion that takes place on the samples that is dependent on the alloy composition. The results obtained by SKPFM on a FSW Al/Al-5754 weldment depict the dependency of the Volta potential differences on the particle number and size of the intermetallic phases.

Summary and Outlook

The results of the corrosion immersion test according to ASTM G 110-92 reveal no intergranular corrosion for the FSW Al/Al-5754 weldment. Nevertheless, there was a kind of pitting corrosion found on the alloy surfaces.

The results of a salt spray test according to ISO 9227 demonstrated advancing corrosion of all FSW Al/steel weldments with exposure time to aggressive media while no corrosion of the FSW Al/Al weldments was noticed.

The results of the electrochemical measurements demonstrate that the OCP of the weldment depends on alloy composition, electrolyte concentration and welding process. The results of potiodynamic measurements depicted in fig 1 were explicit in revealing differences in the electrochemical response with respect to breakdown potentials of the materials, depending aggressive medium concentration and slightly on the alloy composition but not on the welding process.

The results of the Scanning Kelvin probe techniques depicted in fig 3 demonstrate that the Volta potential of the substrate depends significantly on the welding process.

The results obtained by SKPFM on a FSW Al/Al-5754 weldment depict the dependency of the Volta potential differences on the particle number and size of the intermetallic phases. From the parent material (AGW), the particle number of the intermetallic phases increases and at the same time the size of the intermetallic phase decreases towards the nugget. In the nugget the intermetallic phases form a kind of network, whereas in the parent material they remain separated. There is a dependency of corrosion susceptibility of the FSW AA15456 material on the concentration of 5 nm sized intermetallic phases in the nugget compared to the parent material [6]. This matter of fact partially correlates with the present results, which was also supported by the microstructural analysis of FSW materials by the group of WKK [7].

Literature

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Project partners:
1. University of Stuttgart, IMWF
2. University of Kaiserslautern, WKK
3. Fraunhofer Institute of non destruktive testing Saarbrücken IZFP