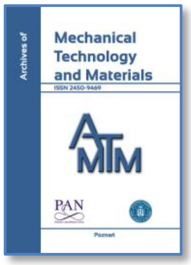
Arch. Mech. Tech. Mater. Vol. 37 (2017) 45-49

DE GRUYTER
OPEN

Archives of Mechanical Technology and Materials
www.amtm.put.poznan.pl



# The influence of sodium chlorides fog on corrosion resistance of heat exchangers used in automotive

**Katarzyna Peta[a]*, Karol Grochalski[a], Adam Piasecki[b], Jan Żurek[a]**

[a]*Institute of Mechanical Technology,Poznan University of Technology, Piotrowo 3, 60-965 Poznan, Poland*

[b] *Institute of Materials Science and Engineering,Poznan University of Technology, Jana Pawła II nr 24 Address, 60-965 Poznan, Poland*

* *Katarzyna Peta, Tel.: +4861-665-22-61,e-mail address: katarzyna.peta@put.poznan.pl*

**ARTICLE INFO**

Received 04 April 2017
Received in revised form 15 May 2017
Accepted 17 May 2017

**KEY WORDS**

brazed joints, aluminum alloys, heat exchangers, corrosion, salt fog

**ABSTRACT**

In the work, the most important factors which influence on the exploitative durability of heat exchangers are classified. Particular attention was paid to the compounds of sodium chloride used in the winter season for road maintenance. In order to determine their impact on automotive heat exchanger corrosion resistance, a test of heaters in a salt chamber which imitates the conditions of their work was realized. It also allows to verify the durability of these products. To evaluate the corrosion changes, observation with the use of light microscopy and scanning microscopy SEM were made supplemented with microanalysis of chemical composition by EDS spectroscopy method. Critical areas in the heat exchangers which are mostly exposed to damage including the formation of local corrosion pits were located and analyzed.

## 1. INTRODUCTION

Heat exchangers used in automotive industry have to meet a number of exploitative requirements resulting from their operating conditions. The most important are: tightness, mechanical durability, heat production and corrosion resistance which is particularly important for products that operate in chemically aggressive environments which cause the transformation of the metal to oxide, salt or other compound resulting in deterioration of its functionality [1-5]. The main environmental factors which impact on the intensity of phenomenon of heat exchange corrosion are: car exhaust and other pollution, sodium chloride compounds, temperature and humidity[6-9].

The corrosion resistance test in the salt chamber is one of the basic tests performed to evaluate the durability of products exposed to the impact of chlorine ions. It allows to imitate the corrosive phenomena occurring during exploitation of automotive heat exchangers in a different conditions. The test in the salt fog is frequently used to control the process of making heat exchangers, including brazing which is the main operation affecting the final quality of these products [10-16].The authors are convinced that the one of main causes of material corrosion deficits is aggressive environment which contains sodium chlorides. In scientific articles the impact on chloride corrosion in automotive heat exchangers was not discussed sufficiently. It is the reason that in this paper the materials were compared directly after the manufacturing process and after corrosion resistance tests in the salt chamber.

## 2. METHODOLOGY

### *2.1. The material for research*

Corrosion resistance tests in the sodium chloride fog with sodium chloride were performed on automotive heat exchangers manufactured of clad tapes which are made of aluminum-manganese AA3003 alloy (tape core material) and aluminum-silicon AA4343 alloy (braze clad material). The chemical composition of materials is presented in Table 1, while basic mechanical properties are shown in Table 2.

DOI: 10.1515/amtm-2017-0007

***Table 1. The chemical composition of AA3003/AA4343aluminum alloys***

| Alloy | Fe | Si | Cu | Mg | Mn | Zn | Al |
|---|---|---|---|---|---|---|---|
| AA3003 | 0.7 | 0.6 | 0.05-0.2 | 0.05 | 1.0-1.5 | 0.1 | rem. |
| AA4343 | 0.8 | 6.8-8.2 | 0.25 | 0.05 | 0.1 | 0.2 | rem. |

***Table 2. The basic mechanical properties of AA3003/AA4343aluminum alloys***

| Material | Tensile strength (Rm) [$N/mm^2$] | Yield point ($Rp_{0,2}$) [$N/mm^2$] | Elongation ($A_{50}$) [%] |
|---|---|---|---|
| AA4343<br>4% (clad)<br>AA3003 | 115.00 | 58.00 | 37.00 |

The corrosion changes of heat exchangers were evaluated mainly in the area of brazed joints which tightness is a basic criterion of exploitative durability. There are made in a protective atmosphere of nitrogen in a radiant-convection oven, realizing sequentially: heat degreasing, flux application, heating, brazing, cooling in nitrogen atmosphere, cooling in air.

### *2.2 Research conditions*

The corrosion resistance tests of heat exchangers in the salt fog are realized according to ASTM G85 standard [17]. For this purpose a salt chamber made of material resistant to this solution with the capacity of 2300 $dm^3$was used. It contains systems which program different corrosive conditions are allowed to imitate the real working conditions of heat exchangers. The device allows not only to steer and control the atmosphere of the salt fog, including its even distribution but also the temperature at which the accelerated corrosion aging of the examined product occurs. The salt fog is produced as a result of the heating and increasing humidity of compressed air and its excess accumulated at the bottom of the chamber is drained out. During the test the air at the pressure of 3.3 bar was pumped to the heat exchangers. Their corrosion resistance was tested in the atmosphere of fog obtained by spraying aqueous solution of sodium chloride of 42g/l strength and pH of2.8-3.0. The constant temperature in the chamber of 50°C was also provided. One study cycle lasted 2h including 0.5h of spraying the salt fog and 1.5h of maintaining the conditions in the device keeping the humidity of more than 98%. Number of cycles was 240 in 480 hours.

In order to compare heat exchangers after the manufacturing process and after the corrosion test in the sodium chloride fog, their tightness was measured. It consists of identification of gas bubble resulting from pressing the compressed air to the object which is submerged in water vessel.

In addition, visual, metallographic and analysis of the chemical composition was performed. For testing OPTA-TECH LAB40 light microscope and Tescan Vega 5135 electronic scanning microscope with PGT Prism 200 Avalonroentgen spectrometer were used.

## 2. RESULTS AND DISCUSSION

After the corrosion resistance test of heat exchangers, apart from visual control, their metallographic structure supplemented by microanalysis of chemical composition was observed. The tests were performed in the area of brazed joint (cooling fluid tube – tape, which increases the surface of heat exchange) because this area is particularly critical point to the leakage of cooling medium and consequently resulting in the failure of engine system cooling or car air-conditioning. The obtained results allowed to determine the impact of the aggressive chlorine ion environment on their corrosive wear.

Figure 1 shows the heat exchangers parts after the process of manufacturing and after the test in the salt chamber. The second one contains the residues of salt particles in between the tapes which block flow of air through the blinds of the tape what worsen the heat exchange between hot cooling fluid and the environment. On the basis of the visual evaluation no damage of the cooling fluid tube in the heat exchanger was observed, which results in leaks in the engine cooling system or air-conditioning.

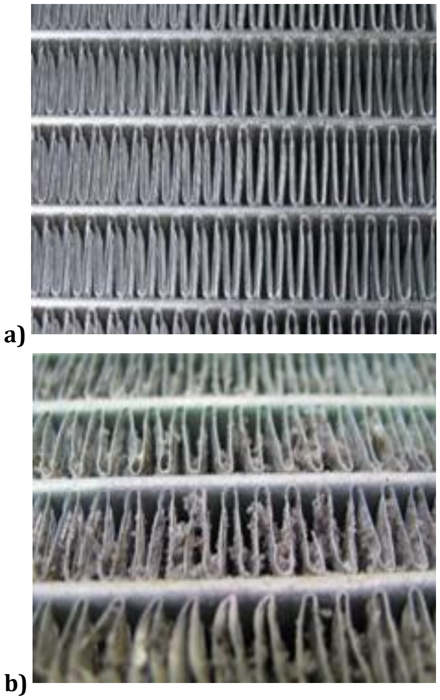


***Fig. 1. The view of heat exchanger parts: a) after manufacturing, b)after test in the salt chamber***

The surface of the heat exchanger after the corrosion resistance test is shown in Figure 2. No corrosion pits were observed in the analyzed area. The presence of crystallized salt layer which closely adheres to the heat exchanger material was indentified. The performed chemical compositions test (fig. 3) in these area showed mainly the presence of oxygen, chlorine, potassium and aluminum as well as fluoride and sodium. On this basis, the crystallized particles were found to be probably sodium and potassium chloride. No damage of passive layer of aluminum oxide on the surface of aluminum alloy was observed, which confirms the presence of oxygen.

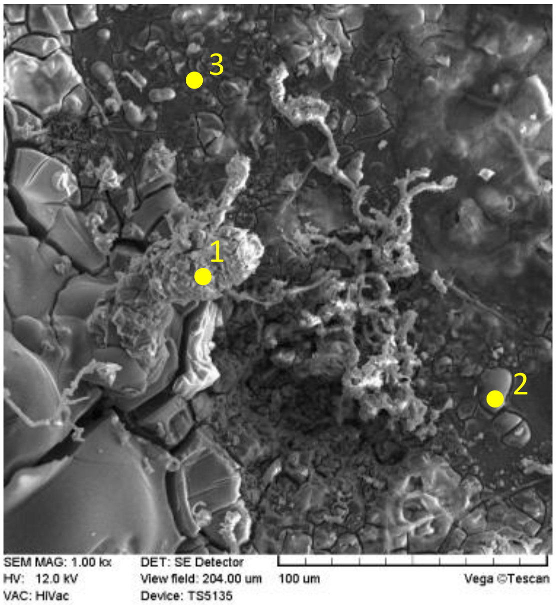
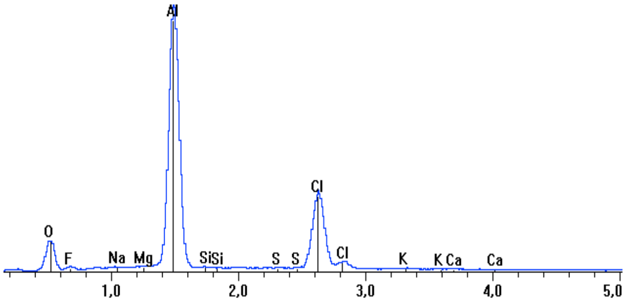
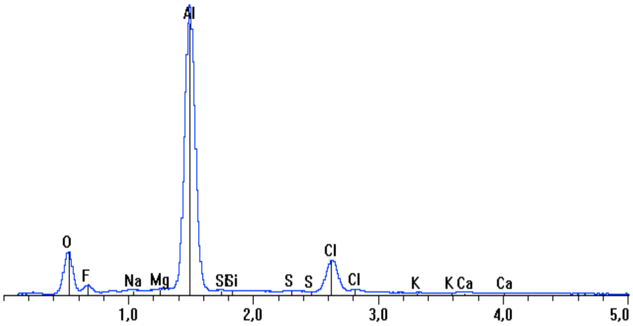


*Fig. 2. SEM image of the heat exchanger surface after the salt spray test with the marking of the EDS microanalysis location*



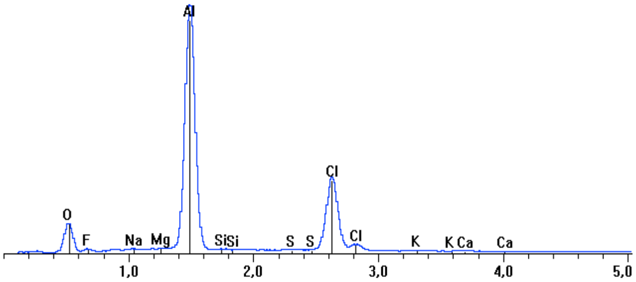
| Element | Line | Wt% | At% |
|---|---|---|---|
| O | KA1 | 26,20 | 39,25 |
| Al | KA1 | 46,80 | 41,59 |
| Cl | KA1 | 24,53 | 16,58 |
| Na | KA1 | 0,31 | 0,32 |
| K | KA1 | 0,26 | 0,16 |
| F | KA1 | 1,19 | 1,50 |
| Mg | KA1 | 0,31 | 0,30 |
| S | KA1 | 0,10 | 0,07 |
| Ca | KA1 | 0,14 | 0,08 |
| Si | KA1 | 0,16 | 0,14 |
| **Total** | | **100,00** | **100,00** |

a)



| Element | Line | Wt% | At% |
|---|---|---|---|
| O | KA1 | 31,69 | 44,30 |
| Al | KA1 | 52,45 | 43,50 |
| Cl | KA1 | 10,74 | 6,77 |
| Na | KA1 | 0,39 | 0,37 |
| K | KA1 | 0,00 | 0,00 |
| F | KA1 | 3,58 | 4,21 |
| Mg | KA1 | 0,34 | 0,32 |
| S | KA1 | 0,23 | 0,16 |
| Ca | KA1 | 0,44 | 0,24 |
| Si | KA1 | 0,15 | 0,12 |
| **Total** | | **100,00** | **100,00** |

b)

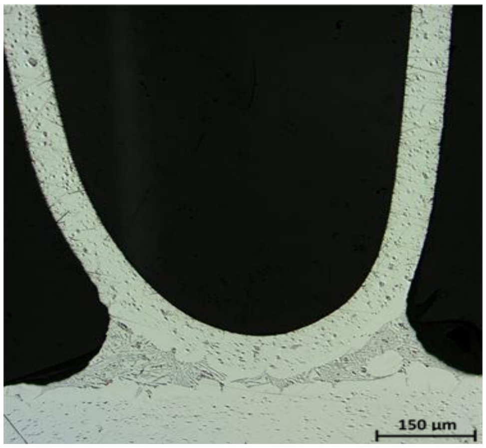


| Element | Line | Wt% | At% |
|---|---|---|---|
| O | KA1 | 26,61 | 39,76 |
| Al | KA1 | 46,24 | 40,99 |
| Cl | KA1 | 24,60 | 16,59 |
| Na | KA1 | 0,35 | 0,37 |
| K | KA1 | 0,27 | 0,17 |
| F | KA1 | 1,23 | 1,55 |
| Mg | KA1 | 0,32 | 0,32 |
| S | KA1 | 0,07 | 0,05 |
| Ca | KA1 | 0,18 | 0,11 |
| Si | KA1 | 0,13 | 0,11 |
| **Total** | | **100,00** | **100,00** |

c)

*Fig. 3. The results of EDS microanalysis after the corrosion test in the salt chamber: a) point 1, b) point 2, c) point 3*

After the initial observation of the heat exchanger surface after the test in the salt chamber, light microscopy images were made in the areas of brazed joint (fig. 4). Numerous deep corrosion pits were identified in the tape which increases the surface of heat exchange. No damage of cooling medium tube was observed. Corrosion changes in the tape area worsen the heat exchange function but did not cause serious leakage of cooling fluid.



a)

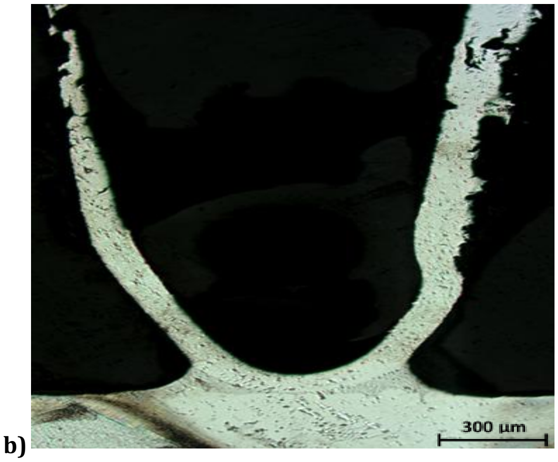


*Fig. 4. Light microscopy images of the brazed joint area: a) after manufacturing, b) after test in the salt chamber*

Figure 5. shows the images of brazed joint (cooling fluid tube – tape which increases the surface of heat exchange) after brazing and after the test in the salt chamber, obtained by the light microscopy method. The identified structural components in the brazed material area are:

- solid silicon solution in aluminum Al,
- coarse, coniferous Al-Si eutectic,
- formation of intermetallic phases, mainly Al-(Fe, Mn)-Si.

No corrosion damage was observed in the brazed joint area. Thus, the formation of potential leakiness in this area under the influence of the corrosive environment of the salt fog appearing during exploitation of heat exchangers is unlikely.

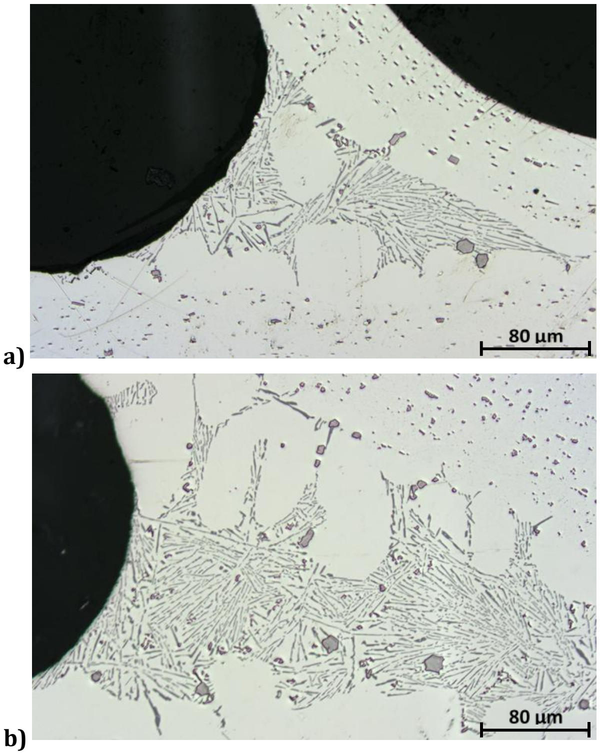


*Fig. 5.The view of microstructure of brazed joint in the automotive heat exchanger: a) after manufacturing, b) after test in the salt chamber*

After corrosion resistance testing of heat exchangers in the salt chamber, the measurements of their leakage were made, which are among the most important when it comes to products in contact with heat exchanger medium. They did not show the occurrence of air leakage to the drained water in the specified object.

## *3.* CONCLUSIONS

The tests in the salt fog are characterized by increased environment aggressive containing sodium chloride in comparison to exploitative environment of automotive heat exchangers. However, they allow the prediction of mechanism of corrosive formation changes of these products. The increased temperature in the chamber and the concentration of the aqueous solution of sodium chloride result in accelerated aging corrosion of heat exchangers.

The obtained results show the proper realization of the manufacturing process of heat exchangers including the choice of materials applied to their production and the parameters of brazing. The corrosion resistance test in a salt chamber confirmed the tightness of the manufactured products. After 240 cycles of testing the corrosion pits were observed in the tape which affects the worsening of the function of heat exchange. However, no damage to the cooling medium tube and brazed joints occurring between them was identified. This demonstrates the tightness of heat exchangers after the salt fog resistance test.

## REFERENCES

[1] **Thulukkanam K.,** Heat Exchanger Design Handbook. Second Edition, CRC Press, Boca Raton, 2013.

[2] **Kim H., Lee S.,** Effect of a brazing process on mechanical and fatigue behavior of alclad aluminium 3005, Journal of Mechanical Science and Technology, 26(7), (2012), 2111-2115.

[3] **Kłyszewski A., Żelechowski J., Frontczak A., Rutecki P., Szymański W., Zamkotowicz Z., Nowak M.,** New Rolled Aluminium Alloy Products for the Automotive Industry, Archives of Metallurgy and Materials, 59(1), (2014), 393-396.

[4] **Pokova M., Cieslar M., Lacaze J.,** Enhanced AW3003 Aluminum Alloys for Heat Exchangers, WDS'11 Proceedings of Contributed Papers, Part III, (2011), 141–146.

[5] **Naser T.S.B., Krallics G.,** Mechanical Behavior of Multiple-forged Al 7075 Aluminum Alloy, Acta Polytechnica Hungarica, (2014), 11(7), 103-117.

[6] **KaiserM.S., DuttaSwagata,** Corrosion Behaviour of Aluminium Engine Block in 3.5% NaCl Solution, Journal of Materials Science and Chemical Engineering 2, (2014), 52-58

[7] **Żaba K., Nowosielski M., Kita P., Kwiatkowski M., Tokarski T., Puchlerska S.,** Effect Of Heat Treatment On The Corrosion Resistance Of Aluminized Steel Strips, Arch. Metall. Mater., 60 (3), (2015), 1825-1831.

[8] **Borowski J., Wendland J., Żak K.,** Zjawisko korozji w aluminiowych wymiennikach ciepła samochodów osobowych, Rudy i Metale Nieżelazne, 55 (9), (2010), 607-613.

[9] **Malik Anees U., Al-Fozan Saleh A., Al-Muaili Fahd,** Corrosion of heat exchanger in thermal desalination plants and current trends in material selection, Desalination and Water Treatment, 55 (9), (2014), 2515-2525.

[10] **Borowski J., Żak K., Samolczyk J.,** Sposoby zwiększania odporności na korozję wymienników ciepła wykonanych ze stopów aluminium, Rudy i Metale Nieżelazne, 54 (8), (2009), 491-499.

[11] **Lou X., Rebak R. B.,** Exposure test evaluates coatings for seawater-cooled heat exchangers, Mater. Performance, 54 (2), (2015), 12-14.

[12] **Zhao Y., Qi Z., Wang Q., Chen J., Shen J.,** Effect of corrosion on performance of fin-and-tube heat exchangers with different fin materials, Exp. Therm. Fluid Sci., 37,(2012), 98-103.

[13] **Oya Y., Kojima Y., Hara N.,** Influence of silicon on intergranular corrosion for aluminum alloys, Mater. Trans., 54 (7), (2013), 1200-1206.

[14] **Braun R.,** Environmentally assisted cracking of aluminium alloys, Materialwiss. Werkst., 38 (9), (2007), 674-689.

[15] **Kannan M. B., Srinivasan P. B., Raja V. S.,** Stress corrosion cracking (SCC) of aluminium alloys, in: V. S. Raja, T. Shoji (Ed.), Stress Corrosion Cracking: theory and practice, Woodhead Publishing, Cambridge, UK, 2011.

[16] **Tierce S., Pébère N., Blanc C., Casenave C., Mankowski G., Robidou H.,** Corrosion behaviour of brazing material AA4343, Electrochim. Acta, 52 (3), (2006), 1092-1100 .

[17] ASTM G85, Standard Practice for Modified Salt Spray (Fog) Testing