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NEW ROLLED ALUMINIUM ALLOY PRODUCTS FOR THE AUTOMOTIVE INDUSTRY

NOWE WYROBY WALCOWANE ZE STOPÓW ALUMINIUM DLA PRZEMYSŁU MOTORYZACYJNEGO

Clad aluminium strips are used in the automotive industry to manufacture parts of heat exchangers. They are characterised by favourable strength properties, good corrosion resistance and susceptibility to plastic deformation, and can undergo surface brazing at a temperature of about 600°C. As a result of studies, the properties of alloys for the production of clad strips have been optimised. Optimising covered the alloy chemical composition and selected parameters such as the metal condition, the mechanical properties and anti-corrosion behaviour, including the methods for corrosion potential equalisation and sacrificial protection. The obtained technological results of the clad aluminium strip production were verified under the industrial conditions of Impexmetal Huta Aluminium Konin S.A. In a laboratory of the Institute of Non-Ferrous Metals (IMN), the clad strips were tested for the pre-assumed functional properties. Mechanical properties were tested, and the structure and corrosion behaviour were characterised. The reactivity of the clad layer was analysed under different technological conditions. The thermal bond produced by these clad layers was tested by simulation of the heat exchanger manufacturing process. As a result of the conducted research it has been found that all the essential characteristics of the clad strips produced under domestic conditions are in no way different from the properties of imported strips, while modification of the alloy chemical composition has contributed to the effective sacrificial protection of heat exchangers made from these strips. Clad aluminium strips are now successfully produced by the domestic aluminium industry. The improvement of materials used for the heat exchangers can contribute to the reduced overall dimensions of these products and increased efficiency, thus leading to energy savings. The results were obtained within the framework of the Task No. ZPB/38/66716/IT2/10 executed as part of the „IniTech" Project.

Keywords: aluminium alloys, clad aluminium strips, brazing, corrosion resistance, automotive industry

Aluminiowe taśmy platerowane znajdują zastosowanie w przemyśle motoryzacyjnym do produkcji elementów wymienników ciepła. Charakteryzują się one korzystnymi właściwościami wytrzymałościowymi, dobrą odpornością na korozję i podatnością do odkształcenia plastycznego oraz zdolnością do zgrzewania powierzchniowego w temperaturze około 600°C. W wyniku badań dokonano optymalizacji właściwości stopów przeznaczonych do produkcji taśm platerowanych. Zoptymalizowano skład chemiczny stopów oraz wybrane parametry takie jak stan materiału, właściwości mechaniczne i antykorozyjne z uwzględnieniem metody wyrównania potencjałów korozyjnych oraz metody ochrony protektorowej. Efekty technologii platerowanych taśm aluminiowych zostały pozytywnie zweryfikowane w warunkach przemysłowych Impexmetal S.A. Huta Aluminium Konin. W warunkach laboratoryjnych IMN przetestowano wytworzone taśmy pod kątem założonych własności użytkowych. Zbadano własności mechaniczne taśm, scharakteryzowano ich strukturę i właściwości korozyjne. Dokonano analizy reaktywności plateru w różnych warunkach technologicznych oraz zbadano wytworzone z ich udziałem połączenia termiczne w warunkach symulacji procesu produkcji wymienników ciepła. W wyniku przeprowadzonych badań stwierdzono, że wszystkie istotne właściwości taśm platerowanych wytworzonych w warunkach krajowych nie różnią się od właściwości taśm importowanych, a odpowiednia modyfikacja składu chemicznego stopów przyczyniła się do zapewnienia skutecznej ochrony protektorowej wymienników ciepła wytwarzanych z tych taśm. Aluminiowe taśmy platerowane wytwarzane są obecnie w krajowym przemyśle aluminiowym. Ulepszenie materiałów stosowanych do konstrukcji wymienników ciepła przyczynić się może do zmniejszenia gabarytów wymienników ciepła i zwiększenia ich sprawności, co prowadzić powinno do oszczędności energii. Wyniki uzyskano w Projekcie nr ZPB/38/66716/IT2/10 zrealizowanym w ramach przedsięwzięcia „IniTech".

1. Introduction (description of preliminary research)

The international literature shows that Al-Si alloy clad aluminium strips are the subject of detailed analysis and optimisation to cope with the needs of modern brazing technology [1-4]. Studies are carried out on strips made from alloys such as AA 3003, AA 3004 [5] and AA 3005 [6, 7] clad with AA 4343 alloy, or soldered with AA 4045 alloy [1,3] or AA 4047 alloy [1,4,5]. The melting point of AA 4343 alloy is 582.5°C, and the brazing process is conducted at a temperature of 605°C [6]. Some experiments are related with the thermodynamic assessment of the brazing process. Studies illustrate the effect of

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high-temperature process on structure evolution in alloys and on the mechanical properties of brazed joints [5-7].

Impexmetal Huta Aluminium Konin S.A. produces strips from Al-Mn alloy (e.g. EN AW-3003) clad with alloys such as EN AW-4343 and EN AW-4045. The strips in heat exchangers [8] are characterised by satisfactory mechanical properties, good corrosion resistance, susceptibility to plastic deformation and surface brazeability. Figure 1 shows microstructure on the cross-section of clad aluminium strips after rolling, heat treatment and high-temperature brazing process. Figure 2 shows an image of the fragments of microstructure of the brazed joints.

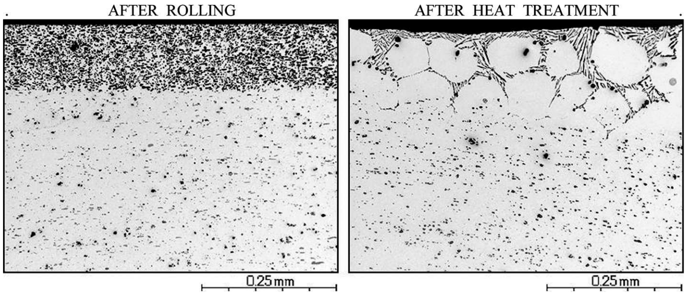

Fig. 1. Images of microstructure on the cross-section of clad strip

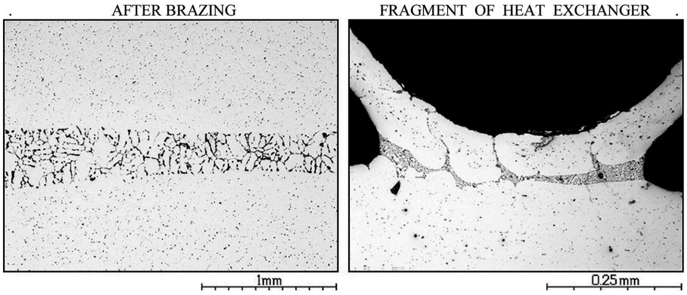

Fig. 2. Images of fragments of microstructure obtained in brazed joints

The layer of deposited metal visible in the images includes silicon precipitates or Al-Si eutectic embedded in aluminium matrix. It was found that the modified form of silumin does not affect the quality of the brazed joints. The core of the strip comprises the precipitates of Al-(Fe, Mn)-Si phase in aluminium matrix.

An important technical feature of the clad strips is their tendency to surface melting of the clad layer at a suitable temperature selected from the range of 570°C - 600°C. In this process, a partial digestion of the clad strip core also takes place. Under properly selected conditions of heat treatment, stable brazed joints are formed. This process is used in a technology of the aluminium heat exchangers manufacture. Products of this type are expected to offer a favourable combination of mechanical properties as well as corrosion and thermal resistance understood as an ability to maintain the strength properties at a required level.

2. Analysis of the thermal resistance of clad strips

Thermal resistance of clad aluminium strips is an important parameter of the heat exchanger production technology and therefore for many years it has been the subject of cooperation successfully conducted by the Institute of Nonferrous Metals in Skawina with industry.

Thermal resistance of commercial aluminium alloy strips made from the EN AW-3003 alloy clad with the EN AW-4045 alloy was tested in a laboratory after one hour-lasting low temperature heat treatment in the temperature range from 210°C to 390°C and after 60 to 90 second lasting high temperature heat treatment at 600°C. Mechanical properties of strips subjected to various heat treatment regimes were measured [9], and using X-ray technique, the progress in recrystallisation was determined [10]. The effect of high temperature heat treatment on the strip core erosion was studied in clad strips disposed vertically and horizontally. Thickness of the clad strip core was determined metallographically. Three variants of alloys were adopted in the studies:

A) vanadium-free commercial alloy,
B) vanadium- and copper-containing alloy with high electrochemical potential,
C) vanadium- and zinc-containing alloy with low electrochemical potential.

Figure 3 shows plotted results of measurements of the yield strength $R_{p0.2}$ [MPa] and unit elongation A_{50} [%] taken on clad strip samples subjected to low temperature heat treatment. The graphs show that the basic mechanical properties of strips made from the commercial alloy and from alloy with the addition of vanadium and zinc are similar. Strips with the addition of vanadium and copper gave much better resistance at high temperature. The difference in temperatures reached about 30°C.

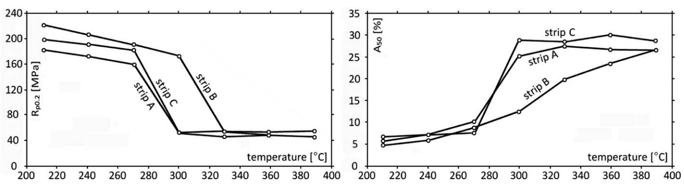

Fig. 3. The results of $R_{p0.2}$ and A_{50} measurements after low temperature heat treatment

Figure 4 shows plotted results of measurements of the yield strength $R_{p0.2}$ [MPa] and unit elongation A_{50} [%] taken on clad strip samples subjected to high temperature heat treatment at 600°C. The graphs show that the basic mechanical properties of strips made from the commercial alloy and from alloy with the addition of vanadium and copper are similar, while strips with the addition of vanadium and zinc have slightly lower elongation and much higher plasticity.

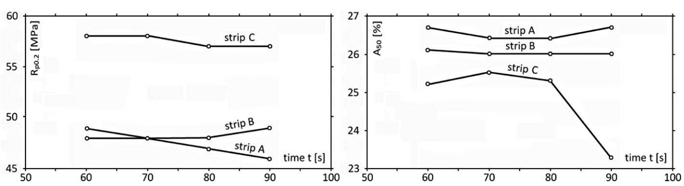

Fig. 4. The results of $R_{p0.2}$ and A_{50} measurements after high temperature heat treatment

Figure 5 shows plotted results of measurements of progress in recrystallisation of the alloy matrix estimated with coefficient of variation V_s of the intensity of diffraction reflection on the peripheral of cones from the adapted photographic method by Debye-Scherrer-Hull [10], used to assess the condition of material in samples of clad strips subjected to heat treatment. The graphs show that the recrystallisation of strips with the addition of vanadium and zinc takes place at temperatures exceeding 280°C, while the recrystallisation of strips containing vanadium and copper at temperatures exceeding 330°C. It has also been found that progress of recrystallisation is the least effective in strips free from the addition of vanadium.

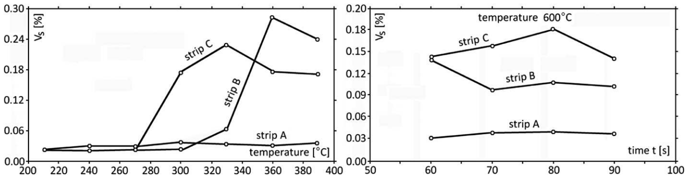

Fig. 5. Progress in the recrystallisation of clad strips

Figure 6 shows plotted results of measurements of the core thickness in upper and lower area of samples of the clad strips subjected to high temperature heat treatment in vertical position and in the sample heat-treated in horizontal position. The obtained results illustrate the destructive effect of the drops of molten clad metal. The graphs show that the flowing droplets of liquid Al-Si alloy etch most effectively the lowermost strip sample area. In this case, after five seconds at the temperature of 610°C, the clad strip core with an initial thickness of 0.9 mm was observed to lose half of this thickness. Moreover, it was observed that at temperatures of approximately 590°C, the strip core thickness was increasing due to the crystallisation of an alpha-Al solution from the Al-Si alloy on the strip core.

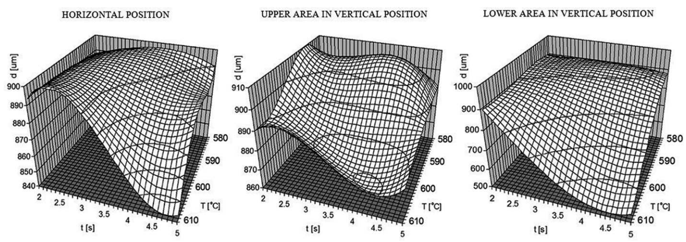

Fig. 6. The results of core thickness measurements after high temperature heat treatment

3. Analysis of the aluminium clad strips corrosion resistance

The corrosion resistance of clad strips was expressed as the weight loss in clad strip samples exposed inartificial atmospheres – salt spray test (NSS) acc. PN-EN ISO 9227:2012. The corrosion potential in the strip samples was measured with AUTOLAB PGSTAT 302 galvanostat in an electrolyte containing 1 M NaCl (58.5 g/l) and 9ml 30% H_2O_2 [11].

Figure 7 shows plotted results of the measurement of the relative mass loss in clad strip samples subjected to low and high temperature heat treatment. The graphs show that vanadium-free strips have the highest loss of weight corresponding to the lowest corrosion resistance. In the high temperature test it has been demonstrated that longer time of heat treatment improves corrosion resistance of the strips.

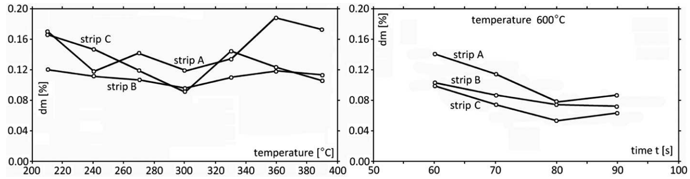

Fig. 7. The results of relative mass loss measurements in strip samples after corrosion test

Figure 8 shows plotted results of the measurement of the corrosion potential in clad strip samples subjected to low and high temperature heat treatment. The graphs show that the corrosion potential to a greater extent depends on the alloying elements, and to a lesser extent on heat treatment conditions. The research has proved that, as expected, the absolute value of the corrosion potential E_k [mV] reaches its maximum level in strips made from the alloy containing vanadium and zinc, and the lowest value in strips made from the alloy containing vanadium and copper. The results of the measured corrosion potential were used in the selection of construction elements for heat exchangers operating in the system of sacrificial protection. The effect of sacrificial protection of the coolant lines was obtained by appropriate selection of the chemical composition of the clad strips.

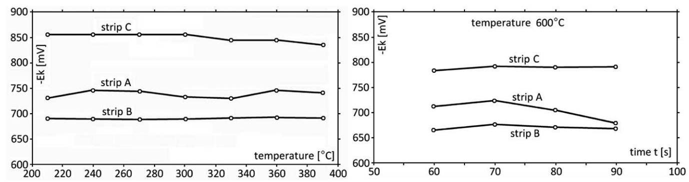

Fig. 8. The results of corrosion potential measurements in strip samples after corrosion test

4. Summary

1. Optimum parameters were sought for the technology of producing selected aluminium alloys to improve the performance characteristics of strips made from these alloys for heat exchangers with particular reference to temperature effects that occur in the brazing process.
2. Chemical composition was modified along with some technological parameters such as the metal condition, the mechanical properties and anti-corrosion behaviour, including the methods of corrosion potential equalisation and sacrificial protection.
3. The research showed that the applied modification of the chemical composition of alloys enabled obtaining high thermal and corrosion resistance of clad strips.
4. The use of improved materials for the construction of heat exchangers has contributed to reduced dimensions of the heat exchangers and to increased efficiency, leading to energy savings.

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