THE APPLICATION OF Ni FOR IMPROVEMENT OF Al-Si-Fe ALLOYS

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Abstract

Iron, often present in secondary material (scrap) forms brittle and hard needles in Al-Si alloys.These particles decrease the mechanical properties of castings. A reliable and economic method of iron elimination from aluminium alloys has not been well-known yet in metallurgical practice. The influence of nickel as an iron corrector (up to 0.7 %) and iron (up to 2.5 %) on the fluidity, microstructure and mechanical properties of the Al alloy with 9.75 % Si, 0.2 % Mg was evaluated. The presence of Ni results in shortening of the needles, but the segmentation of β needles was not observed. Improvement of mechanical properties was observed despite of low affecting of microstructure.

Keywords: *Al-Si alloy, nickel, iron, microstructure.*

1. Introduction

Life Cycle Assessment (LCA) is a scientific tool for the systematic evaluation of the environmental impacts of a product or service system through all stages of its life cycle "from cradle to grave" (mining and extraction of raw materials, fabrication, transportation, use and recycling/ /disposal). The purpose of life cycle assessment is to define the scope of all environmental impacts associated with the product during its life cycle and to identify and reduce aspects with the most significant environmental impacts. Life Cycle Assessment is intended for broad use throughout the industry with a view to assess and stimulate environmental improvement in production processes and product development. Today, life cycle assessment is increasingly developed in metallurgy. It is related to new recycling technology, metal extraction from secondary materials and to fact, that metal production belongs mostly to large environmental pollution sources [1].

A very significant problem of secondary material (scrap) exploitation for aluminium casting alloys is content of iron. The negative influence of iron on the mechanical and technological properties is more significant than that of other secondary elements, frequently occur in aluminium alloys.

Iron content 0.3 ÷ 0.5 % hinders die soldering – the sticking of casting with chill mold, increases strength, hardness, fluidity and mechanical properties at high temperatures. The iron content above 0.5 % is undesirable, because it effects the segregation of brittle and hard intermetallic phases.

Under non-equilibrium conditions the Al-Fe-Si compound crystallize in the needle form during the earlier stages of solidification and the "Chinese script" form during the later stages of solidification. Extra - hazardous are long needles of $FeSiAl_5$ (β phase), penetrating aluminium matrix and eutectic cells. This phase effects the premature failure of the castings by notch effect. The decreasing of cooling rate shifts the start of needles segregation to the lower iron content. High concentration of iron in Al-Si alloys in addition increases hardness, but it decreases corrosion resistance, fluidity and, in the first place, plastic properties [2, 3].

The negative effect of ir on can be partly eliminated by superheating of the melt or increasing of cooling rate. A reliable and economic method of iron elimination from alluminium alloys has not been well-known yet in metallurgical practice. The project of construction for continual removal (continual refining) of iron from the Al-Si alloy by precipitation and sedimentation of particles of the iron-rich intermetallic phases was presented [4]. It has been stated that there is a possibility of removing iron from an AlSi11 alloy containing 2 ÷ 3 % Fe up to 0.6 % Fe at one stage or at two stages by introducing an appropriate addition of manganese which affects the yield of refined melt.

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The negative effect of iron can be eliminated by addition of suitable corrector, whose compounds with aluminium, silicium and iron segregate in less harmful shape (skeleton shaped particles or „Chinese script“) than needles. Cobalt, used as iron corrector in former times, is practically replaced by more cheap manganese at present day. Chromium, vanadium, molybdenum or beryllium are also used.

The aim the work is evaluation of nickel application as the iron corrector. Nickel in form of $FeNiAl_9$ slightly increase the Al-Si-Fe alloy's strength at both room and elevated temperatures, but only if nickel acts as an iron corrector; otherwise nickel reduces ductility, fluidity and corrosion resistance, especially in alloys containing more than 5 % Si. Nickel reduces the coefficient of thermal expansion of aluminium based alloys; nickel and iron together in Al-Si alloys enhance the alloy's resistance to attack by high temperature water and by steam [3].

The influence of iron and nickel on the microstructure, fluidity, hardness, ultimate tensile strength and plasticity of Al-Si castings was evaluated.

2. Description of material and work methodology

The material used in experiments besides Al contained (in wt. %): 9.75 % Si, 0.2 % Mg, 0.0, 0.2, 0.4, 0.7 % Ni and 0.26 - 1.9 % Fe. The atomic absorption method on the spectrometer Perkin Elmer 306A was applied for chemical analysis.

The alloy was melted in the graphite crucible in the electric resistance furnace. Nickel and iron were added in the form of the master alloys AlNi8.5 and AlFe10. AlSiSr10 master alloy was used as modifier. Final Sr content, 0.015 % was sufficient for modification of eutectic Si. The melt was cast (pouring temperature 760 °C) into the steel chill mold "lyre" with six "risers" with graduated diameter for fluidity test and into the chill mold for mechanical properties tests. The index of fluidity Y_z was calculated according to [5]. The temperature of preheated molds was 80 °C, the cooling rate of the castings was 18 $°Cs^{-1}$.

The hardness HV10 was evaluated according to STN 42 0374 (ISO 6507-1). The tensile tests were carried out according to STN 42 0310 (six specimens for every content of iron and nickel). Polished metallographic samples were etched 25 % H_2SO_4 at 7 5°C and consequently 0.5 % HF. The morphology of eutectic Si was evaluated according to STN 42 0491. The analyzer LINK ISIS was used for analysis of structural particles composition by EDX method.

3. The analysis of microstructure

The dendrites of aluminium matrix: length 50 μm on average (up to 300 μm), width 10 - 15 μm. Eutectic silicium is globular, ϕ 1-3 μm, the interparticle spacing λ_β = 1.3 ÷ 1.75 μm. The length of rare needles of eutectic silicium does not exceed 10 μm.

Alloy with **0.0 % Ni**: Rare grey – rusty needles of intermetallic phase Fe_2SiAl_8 (α – phase) with the length between 5 and 20 μm and width up to 3 μm can be seen in eutectic cells up to 0.4 % of iron. Higher concentration of iron results in segregation of sheaf - shaped clusters of needles with the length up to 100 μm, above all in dendrites of aluminium. Long needles of intermetallic phase $FeSiAl_5$ (β – phase), overshooting eutectic cells and dendrites of aluminium matrix with length up to 700 μm segregate when the iron content is above 1.5 %, Fig. 1.

Fig. 1. The needle of β phase – $FeSiAl_5$

Alloy with **0.2 % Ni**: Grey – rusty needles of intermetallic phase (the composition, similar to Al_2SiAl_8 is in Table 1) with length up to 15 μm can be seen in eutectic cells up to 0.6 % of iron. The concentration of iron above 1 % results in segregation of sheaf - shaped clusters of needles with the length up to 80 μm, mainly in dendrites of aluminium matrix. The additional increasing of the iron content effect the segregation of high density needles with the average length 30 μm in both in aluminium matrix and in eutectic cells. The overshooting β needles appear at 1.3 % Fe, their length is 100 ÷ 600 μm.

Tab. 1

Chemical composition of the α and β needles

	Al (%)	Si (%)	Ni (%)	Fe (%)
needle of α phase	70.9	11.5	2.5	15.2
needle of β phase	61.0	11.8	1.5	25.7

Alloy with **0.4 % Ni**: Isolated needles with length up to 5 μm and skeleton – shaped particles ϕ 20 μm can be seen in eutectic cells up to 0.8 % of iron. The concentration of iron above 1.1 % results in segregation of sheaf - shaped clusters of needles with the length up to 80 μm. The additional increasing of the iron content effects the segregation overshooting β needles up to 200 μm and dense network of traversing needles up to 30 μm.

Alloy with **0.7 % Ni**: Sporadic needles of intermetallic phase with length up to 5 μm up to 0.8 % Fe. Higher Fe content results in high density needles up to 50 μm. The length of overshooting β needles (the composition, close to $FeSiAl_5$ is in Table 1) increases in proportion to iron content and is about 300 μm at 2 % Fe and about 1200 μm at 2.5 % Fe.

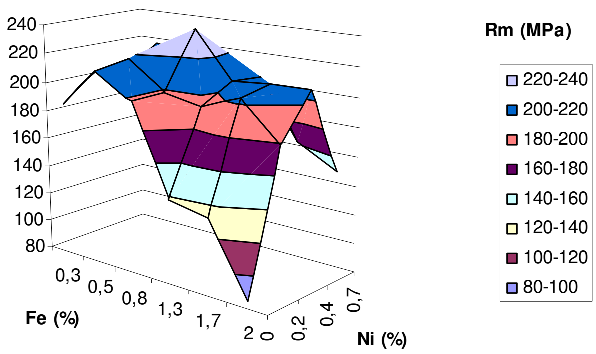

Fig. 2. The influence of Ni and Fe content on R_m

4. The influence of alloy composition on mechanical properties and fluidity.

The influence of iron and nickel on the properties of alloy was tested by Analysis of Variance (ANOVA, a part of software package EXCEL, significance level α □□□= 0.05). The two factor analysis without replication evaluated the statistical significance of iron (factor 1) and nickel (factor 2) on the ultimate tensile strength (Rm), ductility (A_5), reduction of area (Z), hardness (HV10), fluidity (Yz), the shape of iron containing particles and the length of α and β needles in microstructure. If p-value $p < 0.05$ the analyzed factor has a statistically significant impact, Table 2.

Tab. 2

ANOVA, p values

	Ni	Fe
R_m	0.00658	0.01407
A_5	0.01057	$7.96.10^{-5}$
Z	0.02285	$2.61.10^{-6}$
HV10	$8.45.10^{-5}$	$7.07.10^{-5}$
Y_z	0.01020	0.08880
microstructure	0.41897	$1.99.10^{-8}$
length	0.26673	0.00073

According to ANOVA nickel has significant influence on strength, ductility, and hardness but negligible influence on microstructure. Increasing content of nickel mildly increases fluidity. However, it is necessary to regard limited capability of fluidity tests [5]. The iron affects all properties beside fluidity.

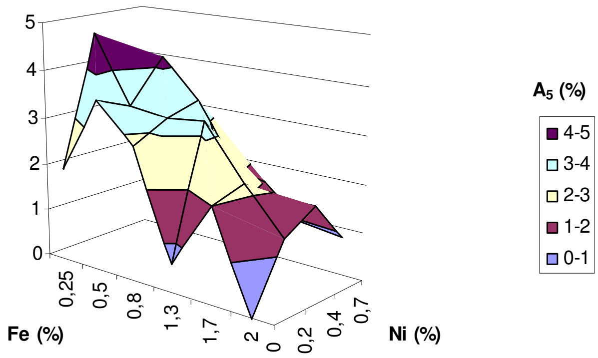

Fig. 3. The influence of Ni and Fe content on ductility

As can be seen on Fig. 2 ÷ 6 the hardness increases with increasing content of iron and nickel. The effect of iron is more significant. Rising iron content significantly decreases strength and plastic properties of casting. Positive effect of nickel for both parameters was observed up to 0.4 %, the effect of higher content is inversed. The best values of R_m were obtained at 0.4 % Ni and 1% Fe.

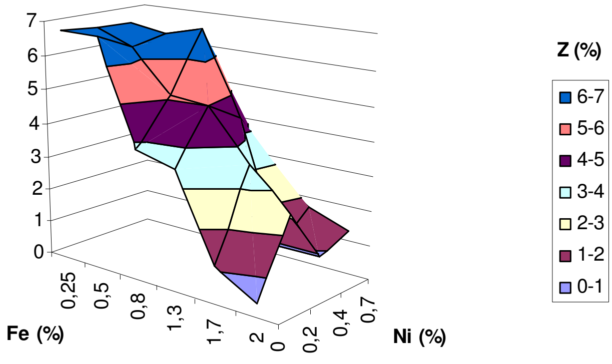

Fig. 4. The influence of Ni and Fe content on Z

The influence of iron correctors (Mn, Ni, Co, Cr, up to 0.7 %) and iron (up to 2 %) on the fluidity, microstructure and mechanical properties was compared. Chromium and manganese have the most significant effect on the shortening of intermetallic needles. The mechanical properties (beside hardness) of Al-Si alloy with iron content are more significantly effected by nickel on the other hand. The influence of cobalt on the microstructure and mechanical properties is marginal. The best fluidity is about 1 %

of iron, independently of iron corrector. Alloy with iron corrector has better fluidity than the alloy without it, as a rule. Iron and iron correctors both increase hardness generally. As for ultimate tensile strength and plastic properties high values (more than 200 MPa) are at all levels of nickel and at 0.2 % Mn and 0.2 % Cr. The strength and plastic properties of alloy with cobalt are lower than those of non-corrected alloy [6].

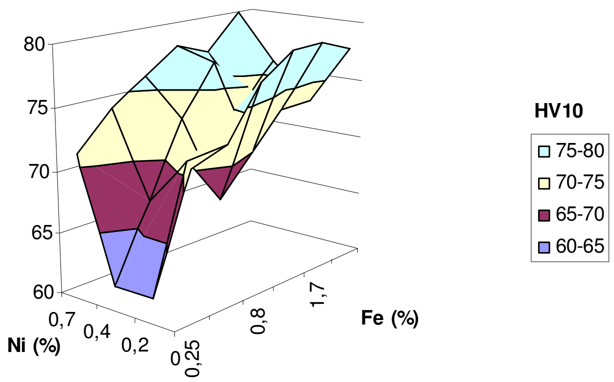

Fig. 5. The influence of Ni and Fe content on HV10

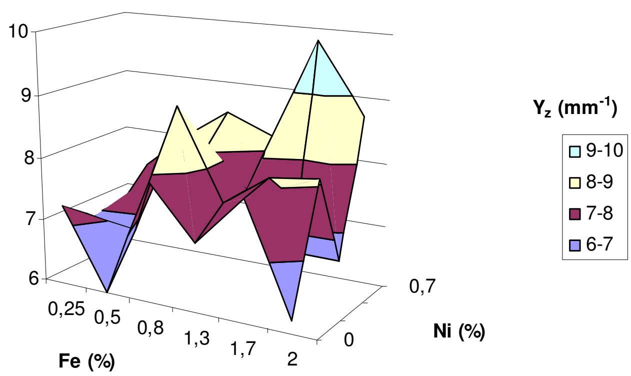

Fig. 6. The influence of Ni and Fe content on Y_z

Nickel as iron corrector allows using iron contaminated aluminium without energy demanding processes (refining or preheating of the melt alloy) perhaps even “dilution” (unavailing waste of high-class aluminium). The synergistic effect of nickel and iron has positive influence on mechanical properties.

5. Conclusions

1. The presence of Ni in analyzed alloy results in shortening of the needles.
2. The segmentation of β needles was not observed.
3. Improvement of mechanical properties was observed despite of low affecting of microstructure.

Acknowledgements

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