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## INFLUENCE CuAl10Fe3Mn2 ADDITIVE ON ULTIMATE TENSILE STRENGTH AND WEAR OF Al-9%SiMg ALLOY

### WPLYW DODATKU CuAl10Fe3Mn2 NA WYTRZYMAŁOŚĆ NA ROZCIĄGANIE I ZUŻYCIE ŚCIERNE STOPU Al-9%SiMg

**Key words:**

silumin, aluminium bronze, Al-Si alloy, ultimate tensile strength, wear.

**Abstract**

One of the most common castings applied in industrial production is aluminium-silicon alloy (ca. 9% Si with Mg). The Al-SiMg alloys have high corrosion resistance, high strength to weight ratio with modifications, very good castability, a low thermal-expansion coefficient, and relatively good wear resistance. These properties make it possible to widely apply the foundry Al-9% SiMg alloy to number of aviation, automotive, and others materials working on tribological applications. Similar to silumins, the aluminium bronze CuAl10Fe3Mn2 is characterized by good mechanical properties and wear and corrosion resistance. This paper presents the research on the treatment of Al-9%SiMg alloy with a composition of CuAl10Fe3Mn2 in different mass ranges. The experiments were conducted by a factor plan  $2^3$  for three independent variables. The main additions were strontium, Al-9%SiMg, aluminium bronze, as well as pure or melted with raw silumin. The effect of the tested additions on the microstructure and tensile strength of the Al-9%SiMg alloy was presented in figures. All analysed parameters (mechanical and tribological) of the hypo-eutectic Al-9%SiMg alloy with tested bronze additions are improved. Based on the analysis of the study results, it was found that the microstructure and tensile strength of the tested alloy are determined through the contents introduced of CuAl10Fe3Mn2 to the alloy.

**Słowa kluczowe:**

silumin, brąz aluminiowy, stop Al-Si, wytrzymałość na rozciąganie, zużycie ścierne.

**Streszczenie**

Jednym z najczęściej stosowanych w produkcji przemysłowej stopów odlewniczych jest stop aluminium-krzem (ok. 9% Si z dodatkiem Mg). Stopy Al-SiMg charakteryzują się wysoką odpornością na korozję, w stanie zmodyfikowanym wysokim stosunkiem wytrzymałości do wagi odlewu, bardzo dobrą leśnością, niskim współczynnikiem rozszerzalności cieplnej, względnie dobrą odpornością na zużycie. Te właściwości umożliwiają szerokie zastosowanie odlewniczego stopu Al-9% SiMg do wielu materiałów lotniczych, motoryzacyjnych i innych pracujących również w zastosowaniach tribologicznych. Podobnie jak w przypadku siluminu brąz aluminiowy CuAl10Fe3Mn2 charakteryzuje się dobrymi właściwościami mechanicznymi, zużyciem i odpornością na korozję. W artykule przedstawiono badania dotyczące obróbki stopu Al-9% SiMg składnikiem CuAl10Fe3Mn2 w różnych zakresach masowych. Eksperymenty przeprowadzono za pomocą planu czynnikowego  $2^3$  dla trzech niezależnych zmiennych. Głównym dodatkiem były: stront Al-9%SiMg, brąz aluminiowy, zarówno czysty, jak i stopiony z surowym siluminem. Wpływ badanych dodatków na mikrostrukturę i wytrzymałość na rozciąganie stopu Al-9% SiMg przedstawiono na rysunkach. Wszystkie analizowane parametry (mechaniczne i tribologiczne) stopu podeutektycznego Al-9% SiMg z badanym dodatkiem brązu zostały poprawione. Na podstawie analizy wyników badań stwierdzono, że mikrostruktura i właściwości mechaniczne badanego stopu są określone przez zawartość CuAl10Fe3Mn2 wprowadzoną do stopu.

## INTRODUCTION

Al-Si alloys have been interesting for industry since 1921, when Pacz introduced eutectic modification methods [L. 1]. Since then, in industrial practice, hypoeutectic and hypereutectic Al-Si alloys have often been used. Despite

the improvement of the microstructure, the traditionally pure Al-Si alloys do not have sufficiently high functional properties. Many attempts have been made to strengthen Al-Si alloys. The improvement of their properties was obtained through the use of technological processes [L. 2–5] and the addition of alloy components [L. 6–10].

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One of the most popular silumin is Al-9%SiMg. The Al-9%SiMg alloy has high corrosion resistance when modified, and a high strength to weight ratio, very good castability, a low thermal-expansion coefficient, and relatively good wear resistance. These properties make it possible to widely apply the foundry Al-9%SiMg alloy to number of aviation, automotive [L. 11], and others materials working on tribological applications [L. 12, 13]. The microstructure of raw Al-9%SiMg alloy consists of a large well deformable alpha phase and a sharp-pointed hard, non-deformable beta phase. These unmodified phases of microstructure composition give the alloy a low tensile strength and an elongation close to zero. This is the reason for not using alloy in this form [L. 14–17]. The addition of copper improves impact toughness as well as corrosion resistance [L. 18]. There are many salts and chemical compounds used in the industry for modification and treatment of Al-Si

alloy [L. 19–27]. There has been a lot of research for the improvement of mechanical properties by technological methods [L. 28–31].

The aim of this study was to simultaneous determine the influence of the mixture with Sr, Al-9%SiMg and CuAl10Fe3Mn2 on the tensile strength and wear of Al-9%SiMg alloy.

## MATERIALS AND METHODS

The Al-9%SiMg alloy, obtained from industrial piglets, was tested in laboratory conditions. The chemical composition of the Al-9%SiMg alloy is presented in Table 1. The alloy was melted in a ceramic crucible in an electric furnace. The experiment had a 2<sup>3</sup> factorial design, and it was conducted on the AlSi9Mg alloy with mixtures (1).

**Table 1. Chemical compositions of Al-9%SiMg alloy**

Tabela 1. Skład chemiczny stopu Al-9% SiMg

Chemical compositions, wt. %								
Si	Mg	Mn	Fe	Cu	Ti	Ni	Zn	Al
9.15	0.29	0.35	0.60	0.15	0.012	0.02	0.2	balance

$$\left. \begin{aligned} X1: Sr &\in < 0.0, 0.06 >, \text{wt}\% \\ X2: Al - 9\%SiMg &\in < 4, 8 >, \text{wt}\% \\ X3: CuAl10Fe3Mn2 &\in < 2, 4 >, \text{wt}\% \end{aligned} \right\} \quad (1)$$

The results were presented in the form of a regression equation with correlation coefficients (2). The significance of correlation coefficients was

evaluated by Student's t-test at  $\alpha = 0.05$  and  $f = 2t_p(f)$  degrees of freedom. The resulting equation was verified by Fisher's test at  $\alpha = 0.05$ .

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{123}x_1x_2x_3 \quad (2)$$

The master alloy was modified in a crucible at a temperature of 750°C for 5 minutes. Cylindrical samples, 8 mm in diameter and 75 mm in length, for metallographic and mechanical and tribological tests were taken after the completion of each modification stage. The tensile stress was tested using a ZD30 universal tensile tester on two samples,  $\phi 6$  mm, for each melting point, according to standard ISO 6892-1: 2016 for metallic materials, Tensile testing Part 1: Method of test at room temperature.

Mechanical tests at each point of the study plan were carried out on 2 samples.

Abrasive wear was tested using a Schopper machine using corundum abrasive disk at 800 grains for the following parameters:

- Abrasive disk diameter  $\phi = 0.158$  m,
- Abrasive disk revolutions  $n = 14$  r.p.m.,

- Holding down force  $F = 98 \cdot 10^{-3}$  N,
- Working distance  $l = 40$  m.

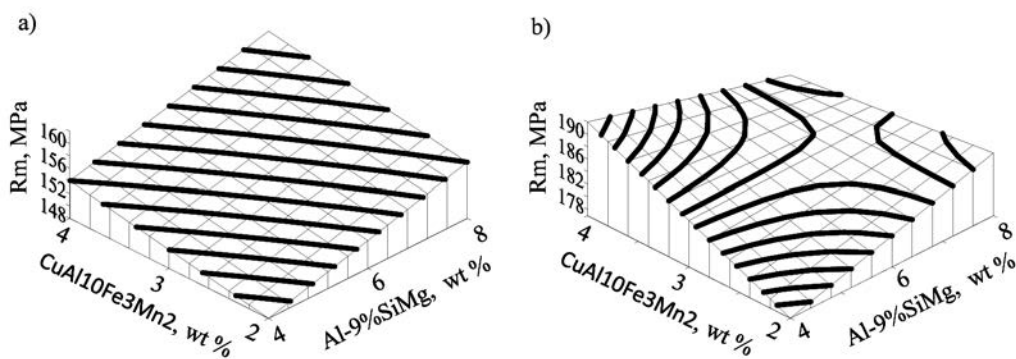
The measurement of wear was by weight with a determined loss in total weight with an accuracy of  $\pm 0.0005$  g by the KERN ALT 310-4 AM scale with an accuracy of 0.00001 g. Wear tests at each point of the study plan were conducted on 4 samples. Due to the tendency of Al alloys to settle on the counter-sample, it was decided to use sandpaper moistened with water for tribological tests.

## RESULTS AND DISCUSSION

Results of the ultimate tensile strength (UTS) of Al-9%SiMg alloy with mixtures (1) are shown at Figs. 1, 2, and 3, and wear results are shown in

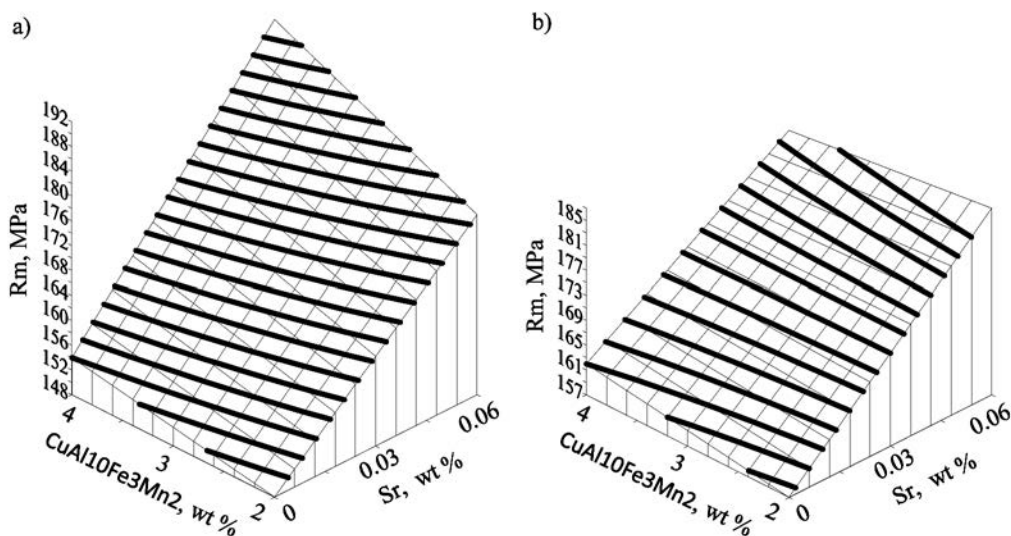
**Figs. 4, 5, and 6.** Due to difficulties with representing functions for three independent variables, graphical drawings for the obtained function were developed from the experimental design on the assumption that each of the analysed modifier components was present at a stable higher (3%) or lower (1%) level while the share of the remaining two components varied. Based on this approach, six graphic forms were developed and two presented (**Figs. 2–4**) for three modifier components. For raw Al-9%SiMg alloy, the average ultimate tensile strength for three test pieces was defined at UTS = 145 MPa and wt. and wear was defined at 0.37518 g. After treatment, the tested silumin based material

(4% Al-9%SiMg + 2% CuAl10Fe3Mn2 +0% Sr) increased in ultimate tensile strength to 148 MPa (**Fig. 1a**) and wear decreased to 0.31943 g (**Fig. 4a**). For the increased modifier to 0.06% Sr, the Rm=178 MPa (**Fig. 1b**) and wear was 0.31035 g (**Fig. 4b**). After increasing the content of the CuAl10Fe3Mn2 to 4%, tensile strength was increased by 16 MPa to 192 MPa (**Fig. 1b**) and wear decreased by 0.04978 g (by 16%) to 0.26057 g (**Fig. 4b**). At this point, the alloy has the best ultimate tensile strength and the best resistance wear. This can also be demonstrated through the use of the graphs below.



**Fig. 1.** The ultimate tensile strength (Rm) Al-9%SiMg alloy with: Al-9%SiMg  $\in$  <4, 8> [%] and CuAl10Fe3Mn2  $\in$  <2, 4> [%] for a) Sr = 0%; b) Sr = 0.06%

Rys. 1. Wytrzymałość na rozciąganie (Rm) stopu Al-9%SiMg z dodatkiem: Al-9%SiMg  $\in$  <4, 8> [%] i CuAl10Fe3Mn2  $\in$  <2, 4> [%] dla a) Sr = 0%; b) Sr = 0.06%



**Fig. 2.** The ultimate tensile strength (Rm) Al-9%SiMg alloy with: Sr  $\in$  <0, 0.06> [%] and CuAl10Fe3Mn2  $\in$  <2, 4> [%] for: a) Al-9%SiMg = 4%; b) Al-9%SiMg = 8%

Rys. 2. Wytrzymałość na rozciąganie (Rm) stopu Al-9%SiMg z dodatkiem: Sr  $\in$  <0, 0.06> [%] i CuAl10Fe3Mn2 <2, 4> [%] dla: a) Al-9%SiMg = 4%; b) Al-9%SiMg = 8%

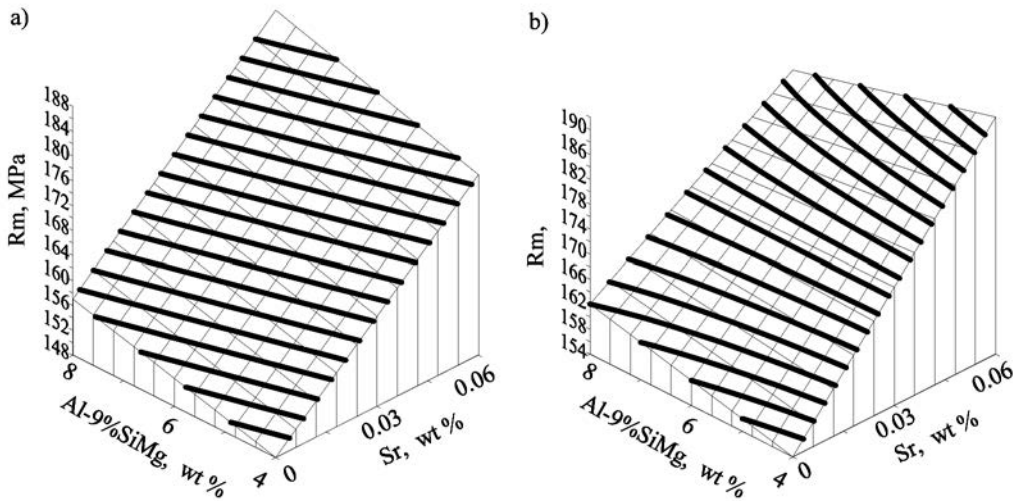


Fig. 3. The ultimate tensile strength ( $R_m$ ) Al-9%SiMg alloy with: Sr  $\in$  <0, 0.06> [%] and Al-9%SiMg <2, 4> [%] for: a) CuAl10Fe3Mn2 = 4%; b) CuAl10Fe3Mn2 = 8%

Rys. 3. Wytrzymałość na rozciąganie ( $R_m$ ) stopu Al-9%SiMg z dodatkiem: Sr  $\in$  <0, 0.06> [%] i Al-9%SiMg <2, 4> [%] dla: a) CuAl10Fe3Mn2 = 4%; b) CuAl10Fe3Mn2 = 8%

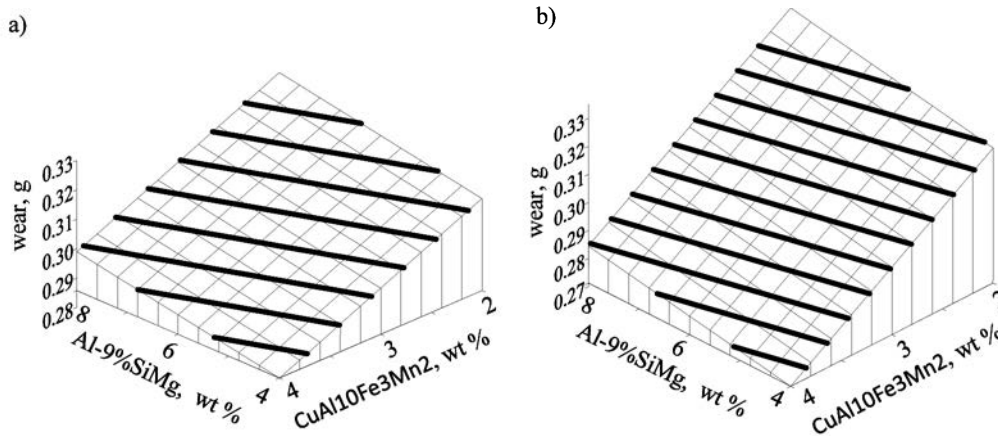


Fig. 4. The wear Al-9%SiMg alloy with: Al-9%SiMg  $\in$  <4, 8> [%] and CuAl10Fe3Mn2  $\in$  <2, 4> [%] for a) Sr = 0%; b) Sr = 0.06%

Rys. 4. Zużycie ścierne stopu Al-9%SiMg z dodatkiem: Al-9%SiMg  $\in$  <4, 8> [%] i CuAl10Fe3Mn2  $\in$  <2, 4> [%] dla a) Sr = 0%; b) Sr = 0.06%

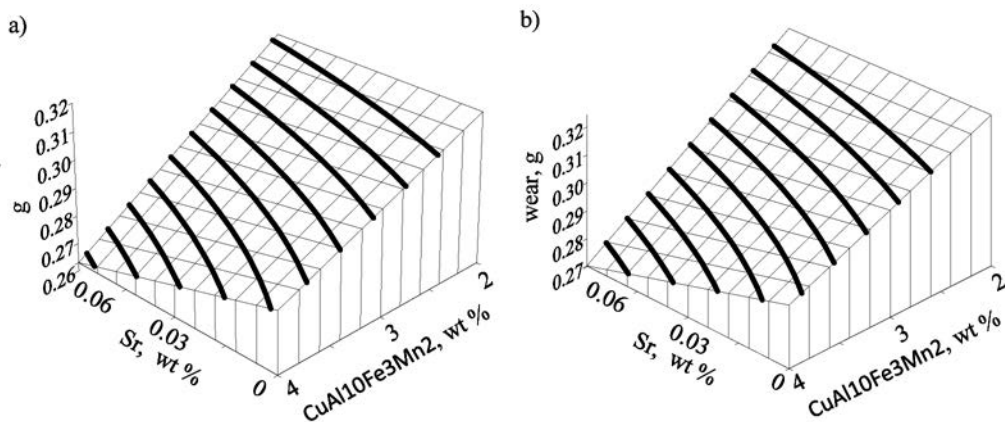
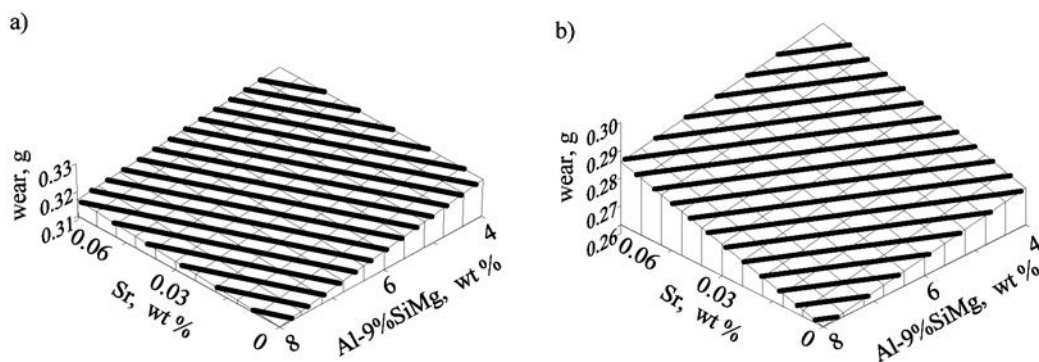


Fig. 5. The wear Al-9%SiMg alloy with: Sr <0, 0.06> [%] and CuAl10Fe3Mn2  $\in$  <2, 4> [%] for: a) Al-9%SiMg = 4%; b) Al-9%SiMg = 8%

Rys. 5. Zużycie ścierne stopu Al-9%SiMg z dodatkiem: Sr  $\in$  <0, 0.06> [%] i CuAl10Fe3Mn2  $\in$  <2, 4> [%] dla: a) Al-9%SiMg = 4%; b) Al-9%SiMg = 8%

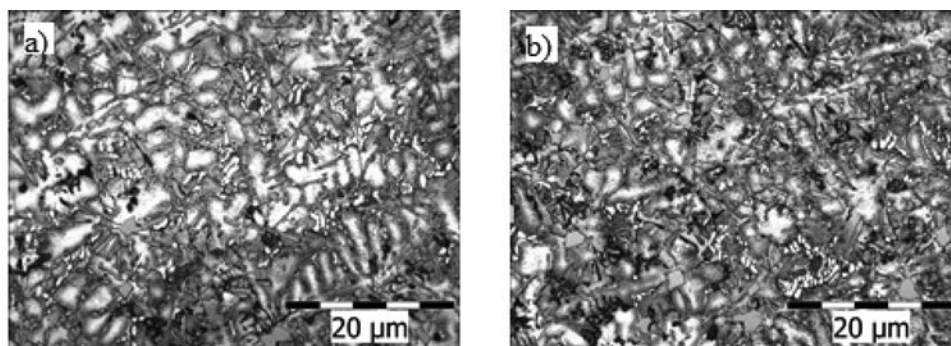


**Fig. 6.** The wear Al-9%SiMg alloy with: Sr  $\in$  <0, 0.06> [%] and Al-9%SiMg  $\in$  <2, 4> [%] for: a) CuAl10Fe3Mn2 = 4%; b) CuAl10Fe3Mn2 = 8%

Rys. 6. Zużycie ściernie stopu Al-9%SiMg z dodatkiem: Sr  $\in$  <0, 0.06> [%] i Al-9%SiMg <2, 4> [%] dla: a) CuAl10Fe3Mn2 = 4%; b) CuAl10Fe3Mn2 = 8%

The microstructure of Al-9%SiMg alloy with 0.06% Sr + 8% Al-9%SiMg + 4% Al10Fe3Mn2 is presented in **Fig. 7a**. The microstructure of Al-9%SiMg alloy with 0.06% Sr + 4% Al-9%SiMg + 4% Al10Fe3Mn2 (the best mechanical properties) is presented in **Fig. 7b**. A little refinement of primary dendrites of  $\beta$  phase was observed after all the processing of the Al-9%SiMg alloy in accordance to the investigation plane (1). The analysed

eutectic had a lamellar structure with a high degree of furcation. Analysing the microstructure of both alloys was noted in both variants with the likely occurrence of the grey needle-granular eutectic  $\beta$  phase and grains of the white  $\alpha$  phase, on a dark background eutectoid  $\alpha + \gamma_2$  and dark precipitates of Chinese writings. Individually occurring separation of  $\kappa$  phase can be observed.



**Fig. 7.** Microstructure of Al-9%SiMg alloy with: a) 0.06% Sr + 8% Al-9%SiMg + 4%Al10Fe3Mn2, b) 0.06% Sr + 4% Al-9%SiMg + 4%Al10Fe3Mn2

Rys. 7. Mikrostruktura stopu Al-9%SiMg z dodatkiem: a) 0.06% Sr + 8% Al-9%SiMg + 4%Al10Fe3Mn2, b) 0.06% Sr + 4% Al-9%SiMg + 4%Al10Fe3Mn2

The strontium causes the most effective ultimate tensile strength of Al-9%SiMg alloy (**Fig. 1–3**). This effect is described in the literature by modifying eutectics [L. 6, 14, 25]. In the absence of Sr, a marked reduction in melt strength was noted. There has also been a slight strengthening of the alloy by the introduction of Al-9%SiMg and CuAl10Fe3Mn2.

The highest wear resistance was observed for the Al-9%SiMg alloy with 4% CuAl10Fe3Mn2 and 0.06% Sr at a level lower of Al-9%SiMg. Increasing the amount of Al-9%SiMg alloy in the mixture has reduced the wear resistance. This effect can most probably be explained

by the large amount of powder mix, which is difficult to introduce into the alloy, and this results in lowering its liquid temperature. Moreover, during the introduction of the mixture, it was noticed that it was more difficult to introduce increasing amounts of Al-9%SiMg and reduce CuAl10Fe3Mn2. This difficulty can be explained by the approximation of the density of the mixture in relation to the density of the base alloy. However, the introduction of a mixture in the form of CuAl10Fe3Mn2 and Al-9%SiMg alloys gives greater effects than the introduction of these solid compounds.

In the absence of a typical chemical modifier (Sr) [L. 6, 25], increasing the contribution of each of the two additives, Al<sub>10</sub>Fe<sub>3</sub>Mn<sub>2</sub> and Al-9%SiMg, increased tensile strength. This effect can be explained through the fragmentation of the eutectic silicon phase. This confirms the interaction improving the microstructure of the treatment alloy. For 0.06% Sr, the proportional increase in tensile strength of the base alloy in relation to the amount of the additive was noted up to 3% Al<sub>10</sub>Fe<sub>3</sub>Mn<sub>2</sub> and 7% Al-9%SiMg (Fig. 1). With a further increase in the amount of both additives, tensile strength was proportionally reduced, which is the “re-modification effect.” Similar dependencies were noted for wear. For its refinement, the microstructure of the alloy resulted in a reduction of abrasive wear. In general, the addition of Al<sub>10</sub>Fe<sub>3</sub>Mn<sub>2</sub> and Al-9%SiMg reduces wear, because Sr

is a modifier, while Al<sub>10</sub>Fe<sub>3</sub>Mn<sub>2</sub> has a relatively high abrasion resistance.

## CONCLUSIONS

1. Research results confirmed the possibility of effectively introducing the CuAl<sub>10</sub>Fe<sub>3</sub>Mn<sub>2</sub> addition to the Al-9%SiMg alloy.
2. The CuAl<sub>10</sub>Fe<sub>3</sub>Mn<sub>2</sub> addition has a more intense effect on the properties of the alloy introduced as a mortar with a basic Al-9%SiMg alloy.
3. The highest wear resistance was observed for the Al-9%SiMg alloy with 4% CuAl<sub>10</sub>Fe<sub>3</sub>Mn<sub>2</sub> and 0.06% Sr at a level lower than Al-9%SiMg.

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