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THE EXAMINATION OF THE EFFECTS OF STRONTIUM CONTENT

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During the experiments AlSi8Cu3 alloy was alloyed with strontium in different concentrations. The effect of strontium on the silicon in the eutectic structure was examined under operating conditions, in case of both higher (> 100 ppm) amount of strontium content than usual in operating conditions and lower (~100 ppm) amount of strontium content, which is not used in practice.
The extent of modification in the test bars casted with thermal analysis and on the final castings was determined with the help of cooling curves and by comparing them to images of reference standards. The reason of using these two methods was to determine the correlation between the levels of modifications determined by the temperature of supercooling, which can be calculated from the cooling curves, and the structure evaluation methods. The mechanical properties of castings which were casted in the given cooling conditions were also examined.
Keywords: aluminium alloys, modification, strontium, thermal analysis

Introduction

Al-Si based alloys are the most commonly used alloys in aluminium light metal foundries, especially in the automobile industry. Depending on the utilisation, the requirements are becoming stricter which are stating that the mechanical properties and the ductility should be around the same value within the casting. The structure of these alloys is influenced by a number of factors, such as the degree of the modification of the silicone in the eutectic structure, the dendrite arm spacing, the porosity and the intermetallic compounds. The mechanical properties can be improved by the optimisation of these parameters [1].

The aim of the modification of the melts of Al-Si alloys is to refine the silicon of the eutectic structure with the addition of a master alloy. Thus, the formation of coarse silicon crystals can be prevented. Sodium, strontium and sodium are the most common elements for the modification of silicon in the eutectic structure.

Aladár PACZ introduced the treatment of Al-Si melts using sodium in 1921 which became the standard modification method of the eutectic structure of Al-Si alloys [2, 3]. After the declaration of the patent, the tests to inquire information on the effects of the various elements on the morphology of the silicon precipitating from the eutectic structure of the aluminium-silicon alloy during the crystallisation. It has been proved that the favourable morphology of the precipitating silicon can be facilitated with not only sodium

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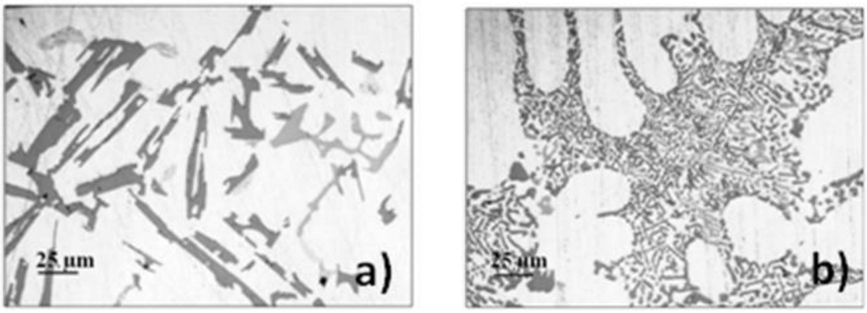
but strontium as well, during a significantly longer time interval (more time for decay). Strontium decreases the diffusion rate of the silicon during the crystallisation of the eutectic structure. Al-Si alloys with hypo- and eutectic structures decrease the eutectic temperature of Al-Si alloy during crystallisation.

Beside strontium, antimony is also used as an inoculant but not as often because of its tendency to create toxic hybrids, it segregates in the secondary alloys during reprocessing and reacts with other elements to create intermetallic compounds.

The morphology of the eutectic silicon is lamellar in the non-modified and spheroidal in the modified Al-Si alloys. If lamellar silicon is precipitated during the crystallisation of the alloy, contraction cavities might develop due to the coagulation of the lamellar silicon. In order to assure the appropriate mechanical properties, the silicon of the eutectic structure should not be lamellar. In case of the modified eutectic structure, the silicon in the structure becomes fine and spheroidal, increasing the tensile strength, elongation and formability. Another parameter influencing the fineness of silicon grains is the cooling rate. However, fully modified structure can only be achieved by increasing the cooling rate and adding further inoculants. The appropriate amount of these so-called inoculants are added to the proper alloys in order to modify the structure [4].

Figure 1 illustrates the morphology of the lamellar non-modified and modified fine-grained Si.



a) Modified *b) Non-modified*

Figure 1

The morphology of the silicon precipitated during the crystallisation of the eutectic structure of the Al-Si alloy [5]

1. Experiments

High purity AlSi8Cu3 (DIN 226.10) alloy was examined during the experiments; the results of the chemical analysis can be seen in Table 1. AlSr10 (pure aluminium wire with 10 wt% Sr) master alloy was used to change the strontium concentration of the melt.

Table 1

The chemical composition of the experimental AlSi8Cu3

Element	Si	Cu	Mg	Ti	Sb	Fe	Mn	Pb	Sn	Ni	Zn
wt %	9.06	2.45	0.31	0.11	0.0011	0.49	0.45	0.03	0.0009	0.03	0.54

The experiments were carried out under operating conditions following the technological steps seen on Figure 2. First, the melt is poured from the smelting furnace into a ladle and then into a holding furnace. Approximately 200 kg melt can be found in the holding furnace ("residue melt") on which the new melt is poured. The next step is the addition of the master alloy (AlSr10), the amount of which is determined by a previous analysis of the composition to achieve the required strontium concentration. In order to increase the purity of the metal and support the homogeneous distribution of strontium, nitrogen degassing treatment was performed during strontium addition and the nitrogen degassing treatment of the melt is performed at the same time. Test bars were casted after the degassing treatment.

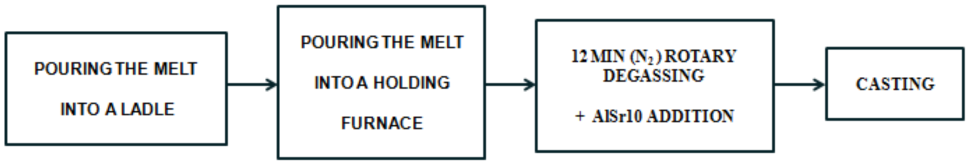


Figure 2
The technology of the operation process

The strontium concentration of the base melt was changed, as well as strontium master alloy was added during the rotary degassing treatment (Table 2). Table 2 contains information on the strontium concentration of the base melt and the strontium concentration modified during the degassing treatment.

Table 2
The values of the strontium concentration of the base melt and after the degassing treatment

Alloys	**Sr concentration of the base melt**	**Sr concentration with AlSr10 master alloy addition during the rotary degassing treatment**
Increased Sr concentration	168 ppm	40 ppm
Decreased Sr concentration	90 ppm	–
	106 ppm	–

Chill tests were carried out at each steps of the experiment in order to monitor the strontium concentration, along with thermal analyses and density index measurements.
The parameters of the experiments are summarised in Table 3.

Table 3
Experimental parameters

The temperature of melting	775±5°C
Casting and alloying temperature	755±5°C
The temperature of the crucible for thermal analysis and density index measurements	200±5°C

2. Results and discussion

2.1. Modification level of the eutectic structure

Reference standard images of the American Foundry Society

Based on the table qualifying the silicon modification of Al-Si alloys prepared by the American Foundry Society (AFS), which can be seen in Figure 3, the degree of modification can be easily determined by a simple comparison [6].

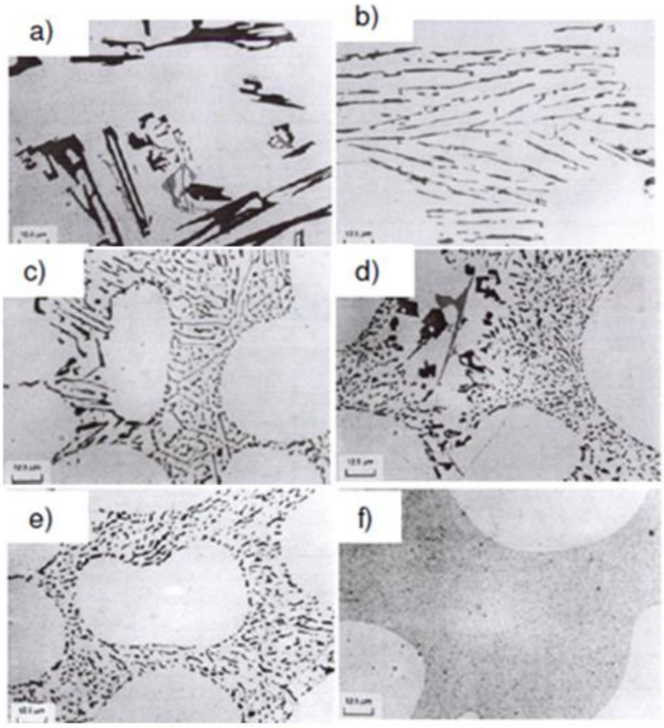


Figure 3
AFS table (A356-AlSi7Mg)
a) non-modified; b) lamellar, c) partly modified; d) non- lamellar; e) modified; f) over-modified [6]

After preparing microstructures from the test bars, 15 photos were taken of the non-etched microsections with 500x magnification using a Zeiss optical light microscope. These were compared to the images from the rating table of the AFS. The degree of modification was determined based on the examined images. Based on the average of the 15 degrees of modification of the images, the degree of modification of the test bars with the given strontium concentration could be obtained.

The degrees of modification and the strontium concentrations at each step of the experiments are shown in Table 4.

Table 4
The degrees of modification and the strontium concentrations

Alloying		**After melting**	**Before degassing**	**After degassing**	**After casting – residue melt**
Sr 168+40 ppm (*Increased Sr concentration)*	Degree of modification	Partly modified	Non-lamellar	Non-lamellar	Non-lamellar
	Sr (ppm)	106	108	107	106
Sr 94 ppm *(Decreased Sr concentration)*	Degree of modification	Lamellar	–	Partly modified	Non-lamellar
	Sr (ppm)	94	–	92	124
Sr 106 ppm *(Decreased Sr concentration)*	Degree of modification	Partly modified	Lamellar	Lamellar	Partly modified
	Sr (ppm)	168	183	202	202

If the strontium concentration decreased below 100 ppm, the originally lamellar structure became non-lamellar by the end of the experiments. Thus, a degree close to modification can be achieved, while the alloy with 106 ppm strontium content is already partly modified in the beginning of the process. This becomes non- lamellar by the end of the process. As the alloy with 168+40 ppm Sr content is lamellar both before and after the degassing treatment, this degree is not acceptable. By the end of the process, the degree becomes partly modified. When there is no extra strontium addition, a consistent lamellar structure is formed.

Thermal analysis

The cooling curves were determined with an MK type data collector. All the data were collected in a table in order to define the cooling curves depending on temperature and time.

The degree of modification is usually calculated based on the following relation from the ΔT supercooling value of the cooling curves [7]:

$$\Delta T_{E,G}^{Al-Si} = T_{E,G,non\ modified}^{Al-Si} - T_{E,G,modified}^{Al-Si} \tag{1}$$

where:
$\mathbf{T^{Al\text{-}Si}_{E,G,NON\text{-}MODIFIED}}$ – solidification temperature of the non-modified eutectic structure
$\mathbf{T^{Al\text{-}Si}_{E,G,MODIFIED}}$ – solidification temperature of the modified eutectic structure
$\mathbf{\Delta T^{Al\text{-}Si}_{E,G}}$ – degree of supercooling

The maximum value of the solidification temperature of the eutectic structure was determined in case of both non-modified ($T_{E,G}^{Al\text{-}Si}{}_{NON\text{-}MODIFIED}$) and modified ($T_{E,G}^{Al\text{-}Si}{}_{MODIFIED}$) AlSi8Cu3 alloys. The degree of supercooling was calculated from two temperatures ($\Delta T_{E,G}^{Al\text{-}Si}$) based on equation (1). The maximum value of the solidification temperature of the eutectic structure of the non-modified alloy with 5 ppm strontium content, casted under laboratory conditions, was used to calculate the value of the supercooling (ΔT). The values of supercooling are calculated via equation (1) and illustrated in Figure 4. The various time intervals are also indicated at each data points.

Based on literature, the structure of eutectic silicon is considered non-modified when ΔT is below 9 °C and modified if the value is higher than that [7].

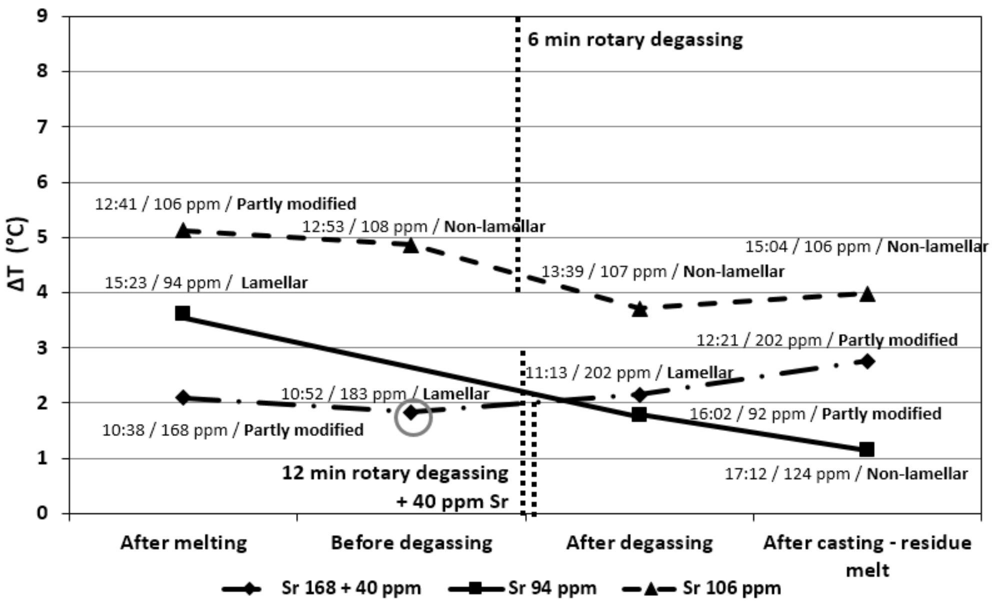
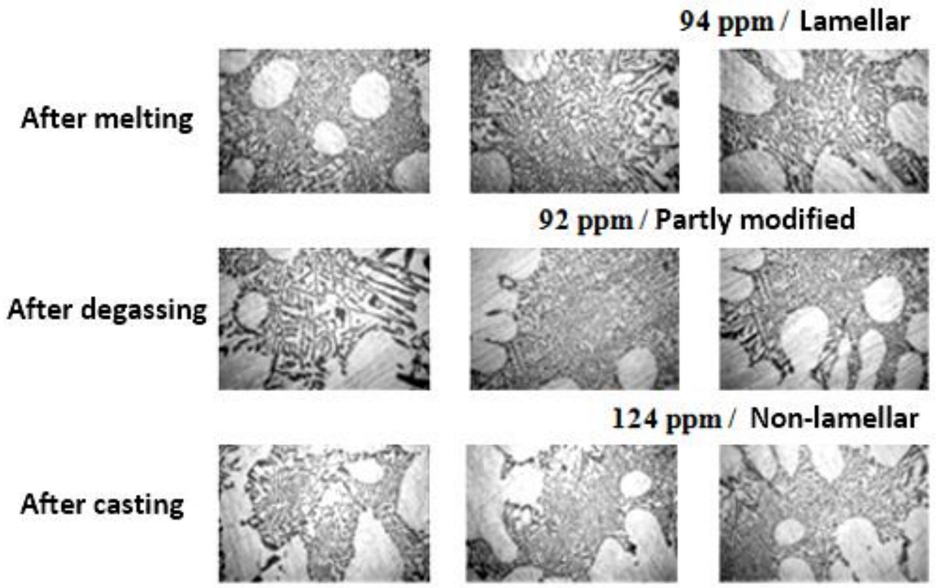


Figure 4
The △T supercooling values calculated from equation (1) with the strontium concentrations and degrees of modification

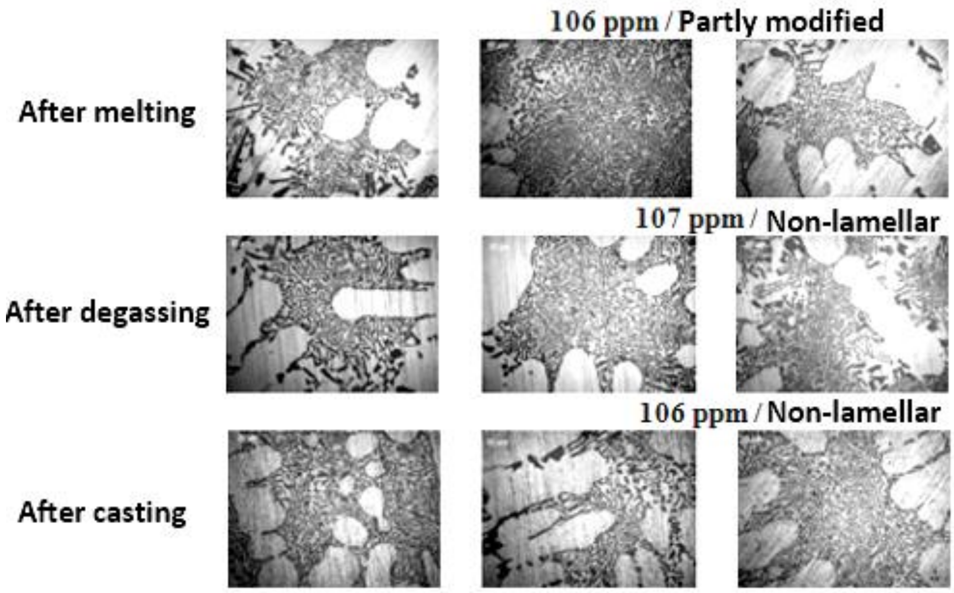
The results showed that the strontium concentration became higher in case of the alloy with 168 + 40 ppm strontium content before degassing treatment without strontium addition because of the 200 kg melt in the holding furnace, the strontium content of which is not determined. The strontium concentration of the melt before degassing and after pouring into the holding furnace was 183 ppm. Just like under operating conditions, 40 ppm strontium was added to the melt with 183 ppm strontium concentration. This only partly dissolved in the system as the strontium concentration was only 202 ppm after degassing. After degassing, the silicon of the eutectic structure is lamellar, so the effect of the added 40 ppm of strontium cannot be observed immediately. However, the supercooling value increases as time passes which means that the effect of strontium is delayed.

In case of melts with lower strontium content (94 ppm, 106 ppm), the supercooling temperature gradually decreases during the different experimental steps. Based on the supercooling values, the effect of the strontium in the melt cannot be observed.

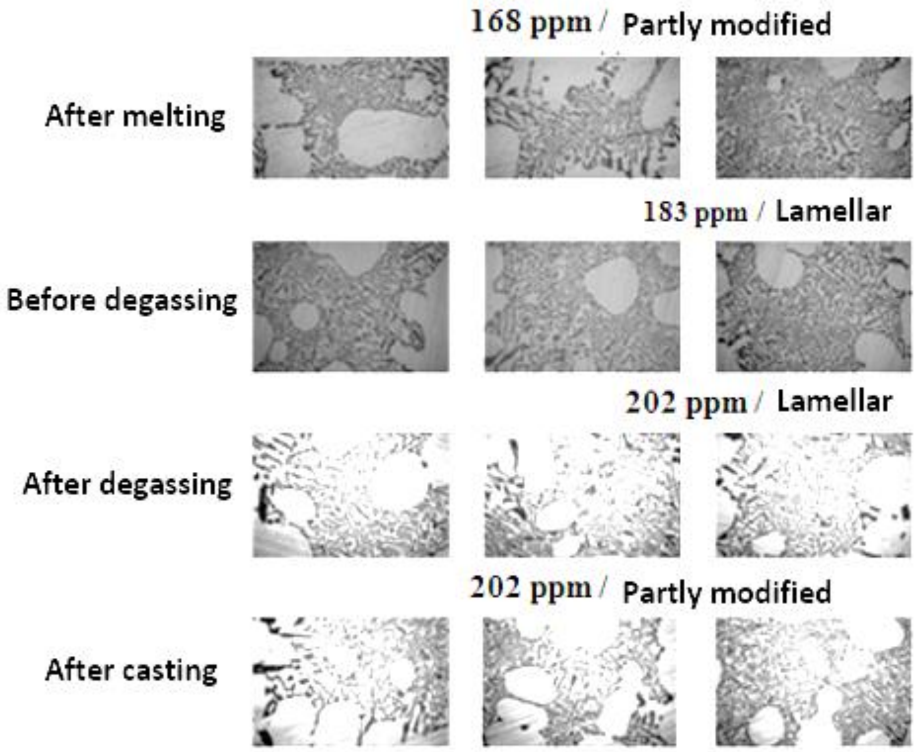
Optical microscopic images of microsections used for thermal analyses, the degrees of modifications determined based on the images and the respective strontium concentrations are illustrated in Figure 5.


94 ppm / Lamellar
After melting
92 ppm / Partly modified
After degassing
124 ppm / Non-lamellar
After casting

a)


106 ppm / Partly modified
After melting
107 ppm / Non-lamellar
After degassing
106 ppm / Non-lamellar
After casting

b)



c)

Figure 5

The degrees of modifications determined with the help of standard images with respect to the Sr concentrations during the different technological steps
a) Sr 94 ppm; b) Sr 106 ppm; c) Sr 168 + 40 ppm

2.2. Mechanical properties

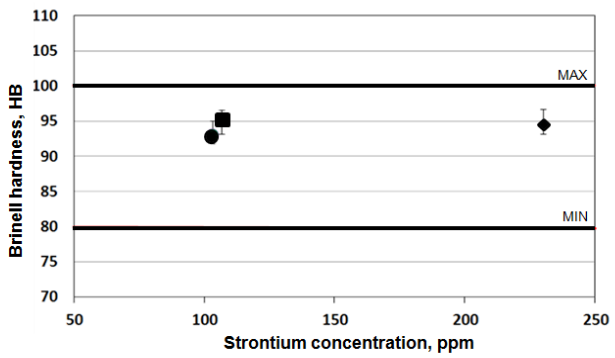


Figure 6

Correlation between the average Brinell hardness and the average strontium concentration

The examination of the mechanical properties of the castings prepared in the pre-defined cooling conditions was carried out.

Brinell hardness was measured using a Ø5 mm ball with 250 kp force applied. In Figure 6, the average of three measurements in case of all castings are illustrated, based on the strontium concentration.

As it can be observed in Figure 5, the values of Brinell hardness are between 80 and 100 HB, as it was expected.

The elongation and tensile strength values were also examined. 9 tensile test specimens were made out of five castings in case of each experiments, and the values are averaged.

Figures 7–8 show the average elongation (A) and tensile strength (R_m) values.

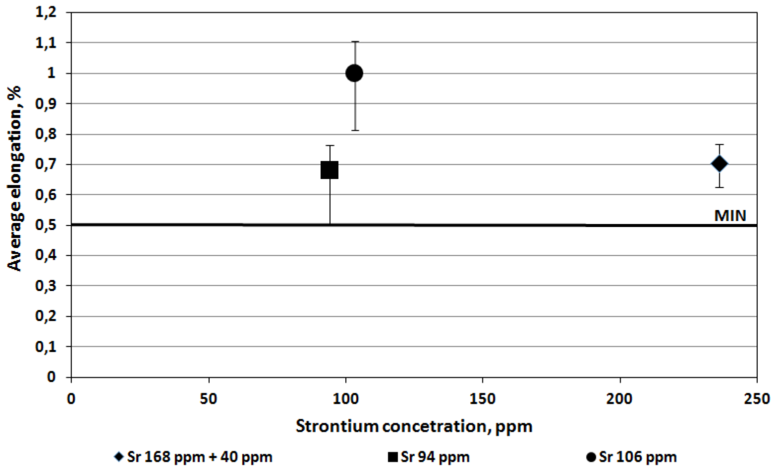


Figure 7
Correlation between average elongation and average strontium concentration

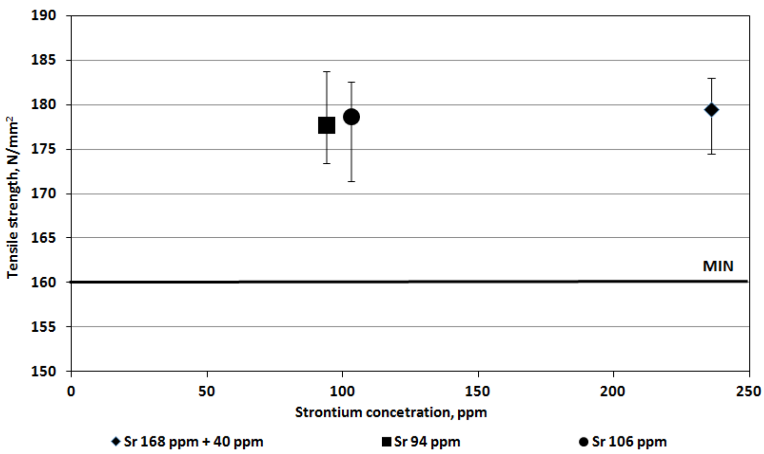


Figure 8
Correlation between average tensile strength and average strontium concentration

The highest value of elongation can be achieved if the strontium concentration is below 100 ppm. The same is true in case of the average yield limit but in case of the tests with 168 + 40 ppm and 106 ppm strontium concentrations, the values are above the minimum. There is no significant difference between the tensile strength values and those are always above the given minimum values.

Conclusion

The effects of variable strontium concentration was analysed in case of AlSi8Cu3 alloy. The examination of the structure determined that optimal modification levels can be achieved in every case examined.

Based on the examination of the mechanical properties, the required mechanical properties can be achieved via all the experiments included in this article despite the difference in certain parameters.

According to the results, starting out with low (~100 ppm) strontium concentration, based on the parameters of the actual experiment, is favourable.

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