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Influence of modifcation on the refinement of primary silicon crystals in hypereutectic silumin AlSi21CuNi

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Abstract
On the paper the influence of modifying micro additives on the refinement of primary silicon crystals in the hypereutectic AlSi21CuNi piston silumin have been examined. As the modifiers there were used micro additives of Phosphorus in the form of AlCu19P1.4 and CuP12 pre-alloys, sulfur in the form of CuS and iron in the powdered form. The modifying micro additives were used separately and together. Micro additions of iron were used together with phosphorus. Sulfur micro addition provided the fragmentation of the primary silicon crystals, but not as effective as the phosphorus micro additive. The best effect of fragmentation of the primary silicon crystals was ensured by the combined addition of phosphorus in the form of AlCu19P1,4 pre alloy with a micro additive of powdered iron which reduced the average size of the primary silicon crystals from 114 µm to 20 µm.

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1. Introduction

The hypereutectic Al-Si alloys are characterized by the presence of large primary silicon crystals in their microstructure. These crystals reach sizes above 100 µm and even above 150 µm. Such large silicon crystals, often with complex shapes, make machining more difficult and have an adverse effect on the smoothness of machined surfaces, especially for piston castings. It also worsens the tribological properties and durability of pistons.

Favorable refinement of the primary silicon crystals in the hypereutectic Al-Si alloys, provides modification treatments that induce heterogeneous crystallization of the primary silicon. It is now generally accepted that an effective inoculant of silicon is a phosphorus micro addition (PONIEWIERSKI, Z. 1966, PONIEWIERSKI, Z. 1989, EIGENFELD, K. 2000, TENEKEDJIEV, N., ARGO, D., GRUZELSKI, J. E. 1990, MÜLLER, K. 1996) that forms AlP phase on Al-Si alloys, which causes the heterogeneous nucleation of silicon crystals. According to some researchers (TENEKEDJIEV, N., ARGO D., GRUZELSKI, J.E. 1990) already a small addition of phosphorus in the amount of 0.001-0.01% results in a satisfactory refinement and even distribution of the primary silicon crystals in the structure of the hypereutectic Al-Si alloys. Some researchers (PONIEWIERSKI, Z. 1966, MICHALSKI, M., ROMANKIEWICZ, F. 2017) claim that the sulfur micro additive also refines primary silicon crystals and modifies eutectic. Other researchers (EIGENFELD, K. 2000, MÜLLER, K. 2000) found that the effect of the refinement of primary silicon crystals can be activated with an iron micro additive that can form FeP phase particles (MÜLLER, K. 2000) and FeP1,8 phase particles (EIGENFELD, K. 2000).

2. Description of the experiments

The authors decided to verify the possibility of refining of the primary silicon crystals with use micro-additives of phosphorus, iron and sulfur using the AlSi21CuNi piston alloy with chemical composition according to Polisch Standards (PN 76 / H-88027). After melting the alloy, it was heated to 800ºC and held for 30 minutes.

Modification treatments were carried out at a temperature of 750ºC. On the table 1 are given the type and amount of the modifying additives that was used on the research.

Phosphorus was introduced into the modified alloy in the form of AlCu19P1,4 and Cup12 pre-alloys. The sulfur was used in the form of CuS sulphide, while the iron was used in powdered form.

The results of the tests are illustrated in Figures 1-18. The effects of the modification were assessed based on the study of the solidification process of samples of the tested alloy by the use of ATD method and the study of alloy microstructure.

Table 1. The influence of modifying micro additives on the dimensions of primary silicon crystals

No of Melt	Type and amount of modifier	The average size of Si crystals [µm]	Te [ºC]
1	Without modification	114	574.9
2	Modif. 1.07% of Al-Cu19P1,4	26	574.4
3	Modif. 1.07% of Al-Cu19P1,4 and 0.04% of CuS	29	553.4
4	Modif. 0.07% of CuS	58	555.8
5	Modif. 0.5% of AlCu19P1,4 and 0.07% of CuS	35	553.0
6	Modif. 1.07% of Al-Cu19P1,4 and 0.02% of Fe	20	550.0
7	Modif. 0.12% of CuP12	43	554.6
8	Modif. 0.12% of CuP12 and 0.02% of Fe	72	553.6
9	Modif. 0.12% of CuP12 and 0.01% of Fe	68	553.9

3. Analysis of the results of experiments

The ATD diagrams for AlSi21CuNi silumin without modification (Fig. 1) is characterized by overcooling of the crystallization temperature of the primary silicon and a slight decrease of the eutectic solidification temperature (574.9° C). A similar temperature of solidification of eutectic (574.4ºC) was demonstrated by the alloy modified with the addition of AlCu19P1.4 (Fig. 3). In other cases of silumin modification (Figures 5, 7, 9, 11, 13, 15, 17), the eutectic solidification temperature decreased (Table 1).

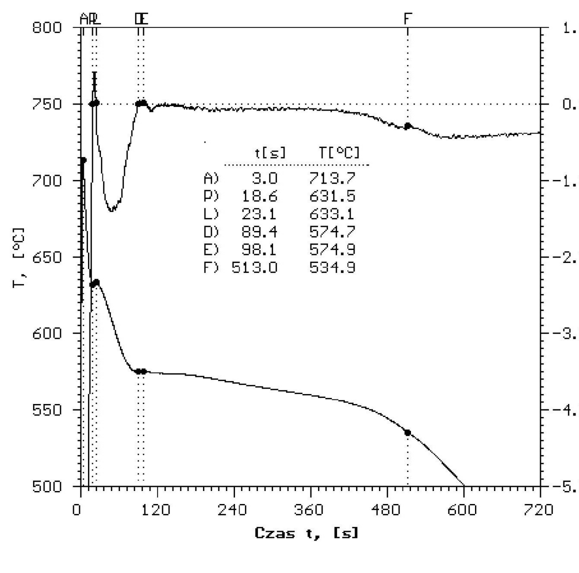


Fig. 1. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi without modification

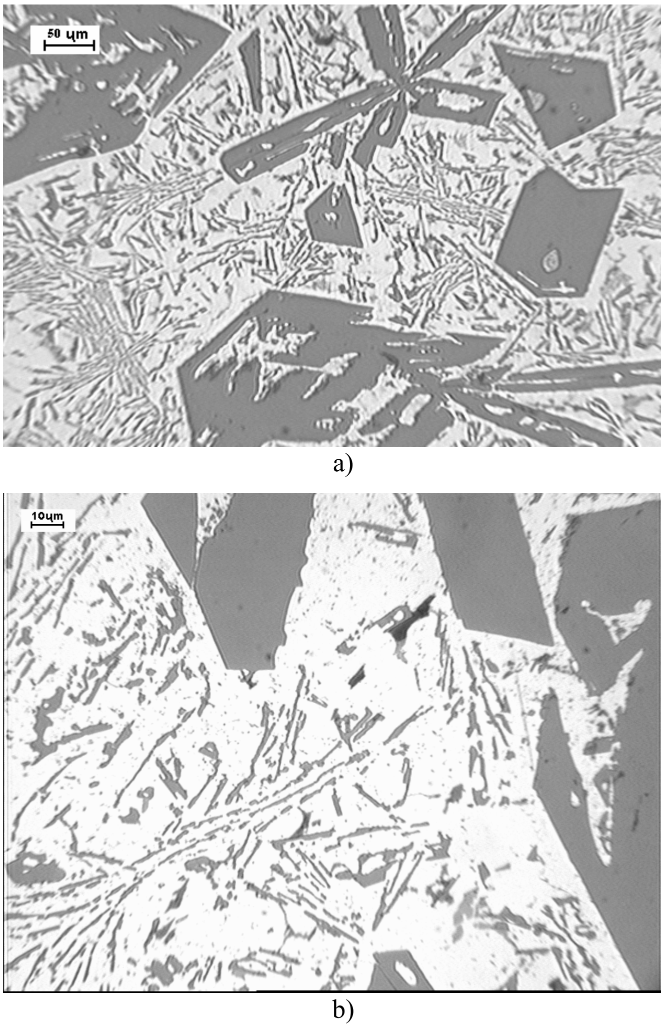


Fig. 2. Microstructure of hypereutectic silumin AlSi21CuNi without modification: a) mag. 100x, b) mag 500x

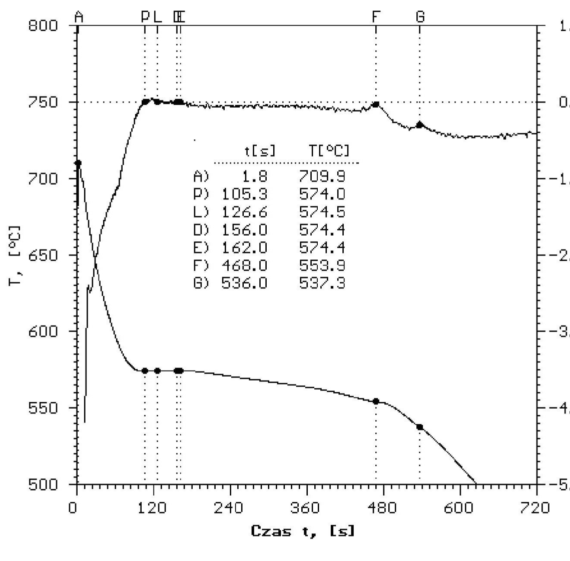
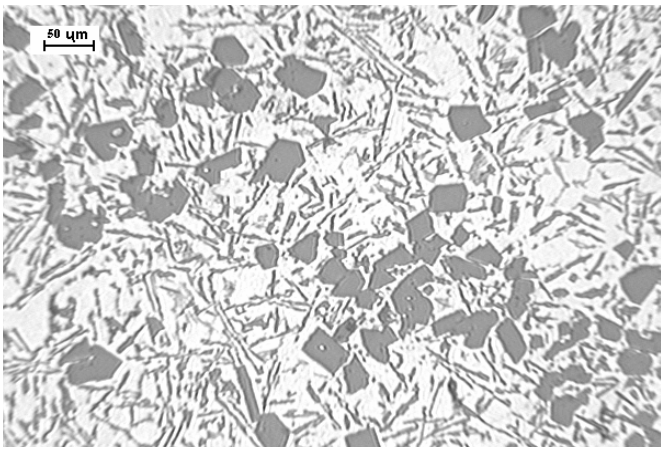


Fig. 3. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 1.07% of AlCu19P1,4



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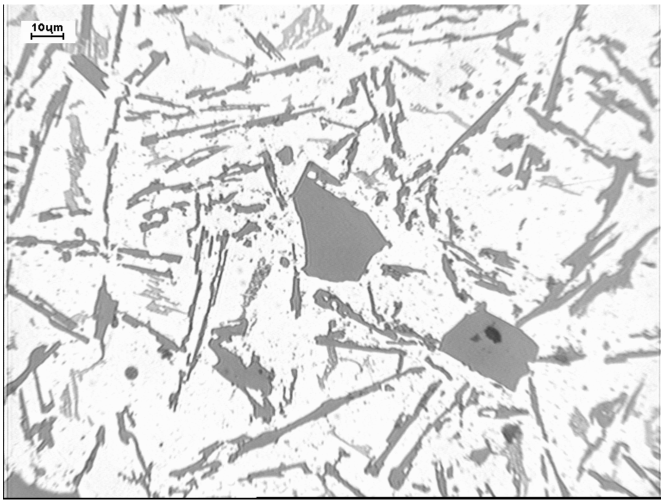

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Fig. 4. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 1.07% of AlCu19P1,4

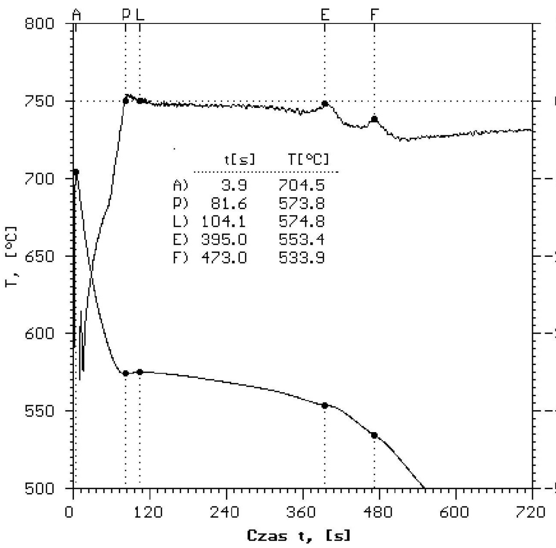
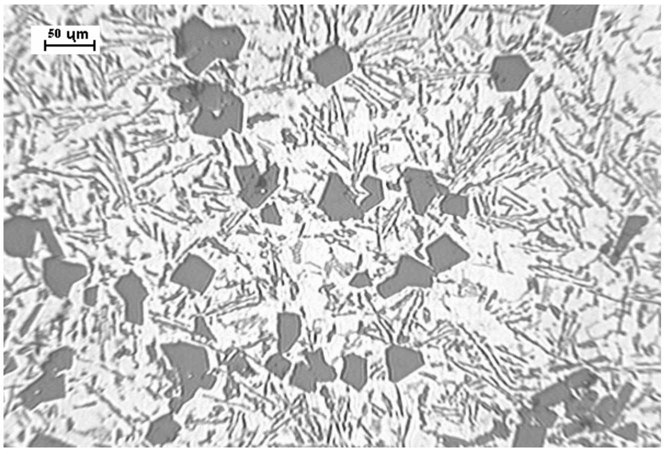


Fig. 5. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 1.07% of AlCu19P1,4 and 0.04% of CuS



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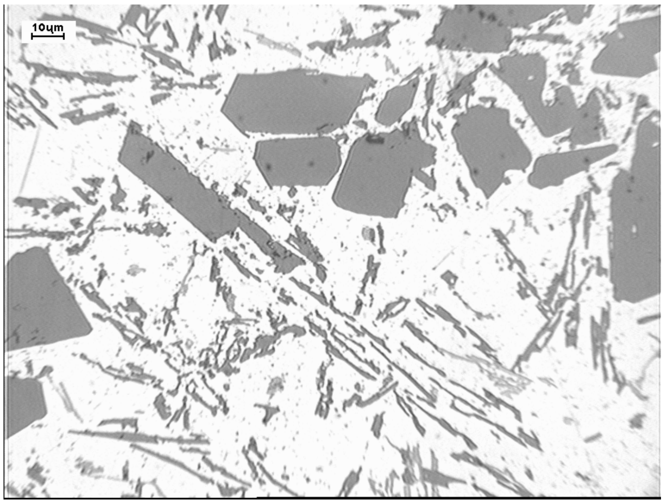

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Fig. 6. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 1.07% of AlCu19P1,4 and 0.04% of CuS

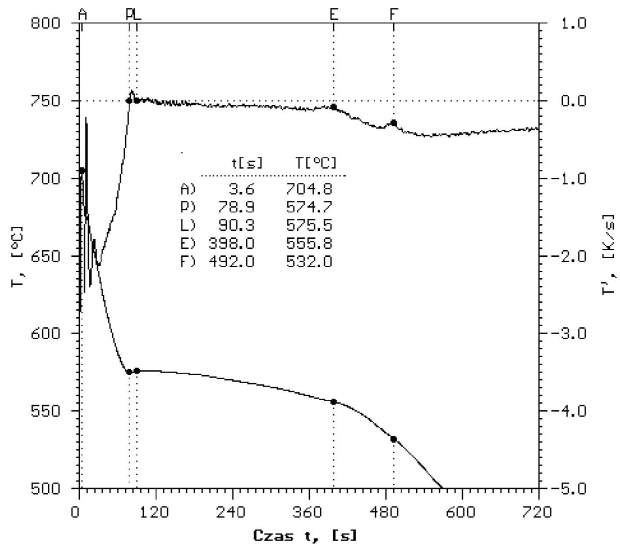
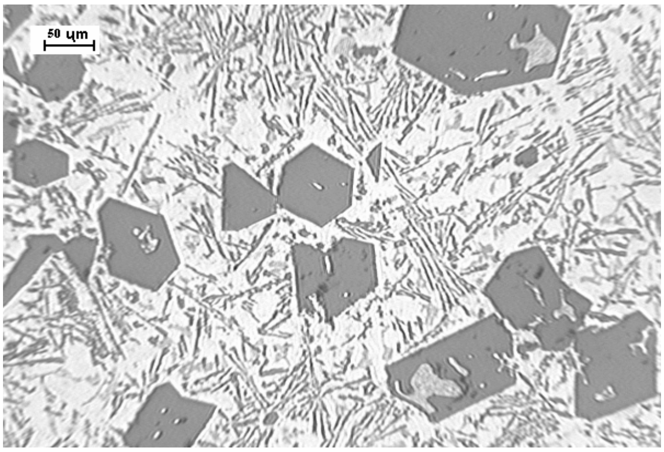


Fig. 7. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 0.07% of CuS



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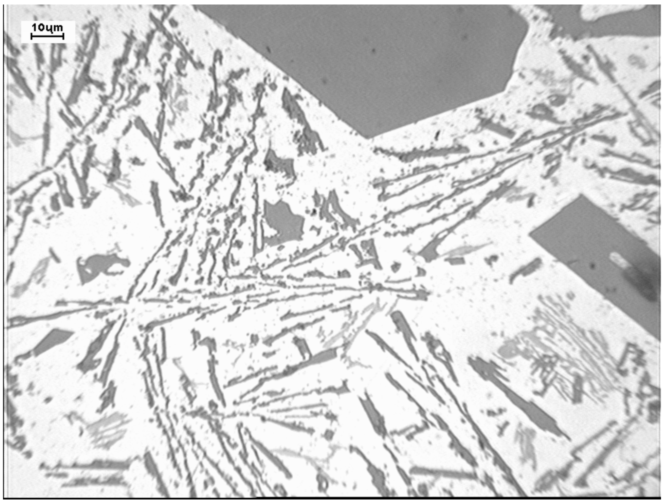

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Fig. 8. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 0.07% of CuS

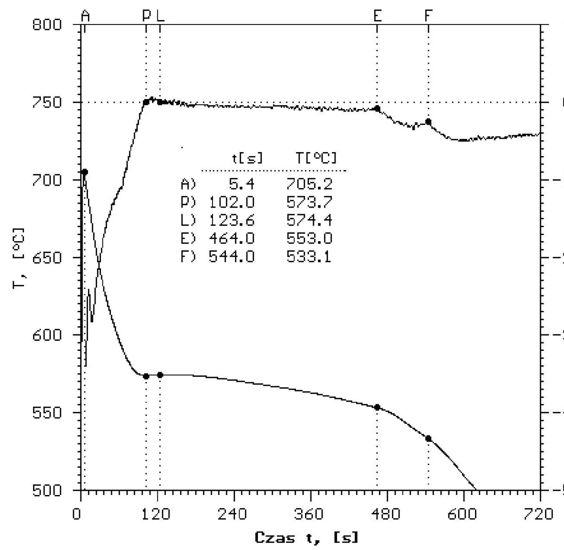
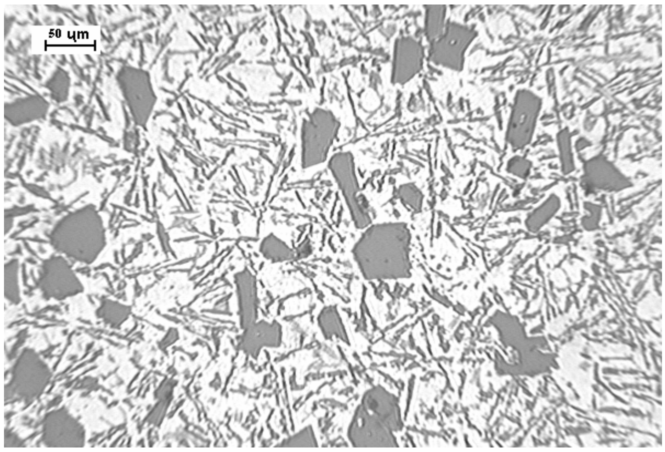


Fig. 9. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 0.5% of AlCu19P1,4 and 0.07% of CuS



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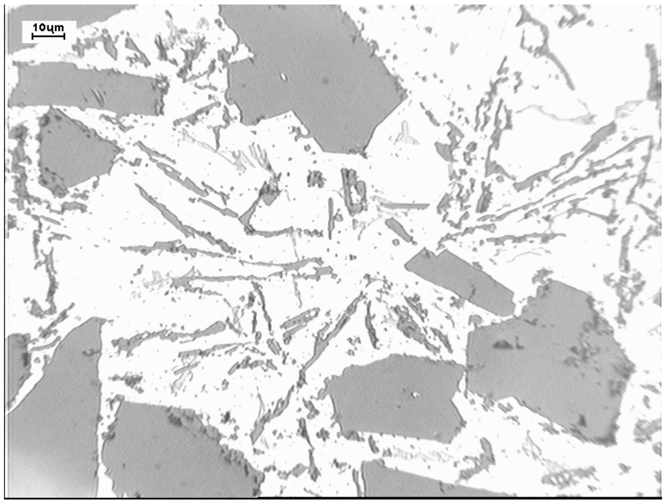


b)

Fig. 10. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 0.5% of AlCu19P1,4 and 0.07% of CuS

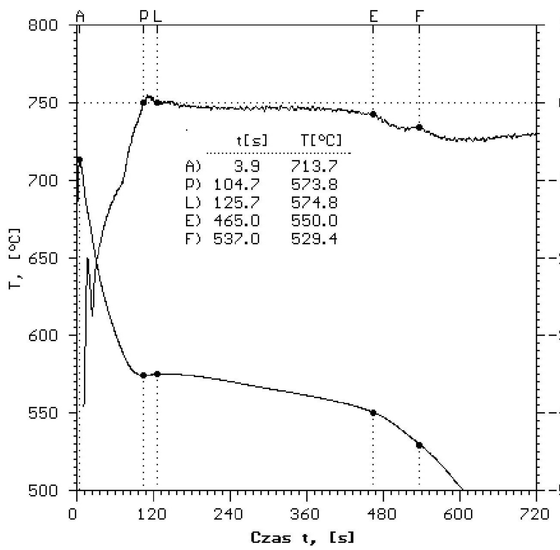
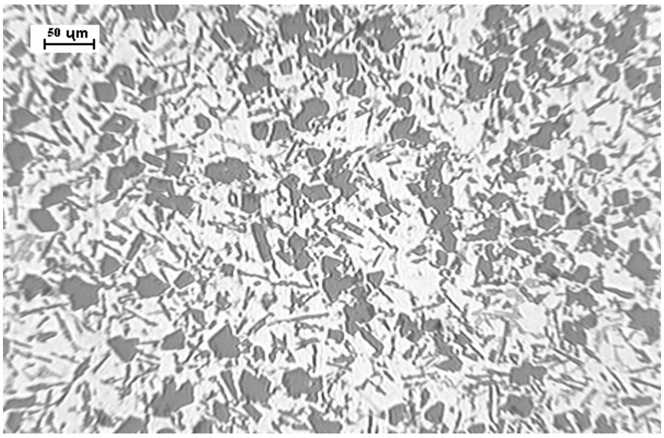


Fig. 11. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 1.07% of AlCu19P1,4 and 0.02% of Fe



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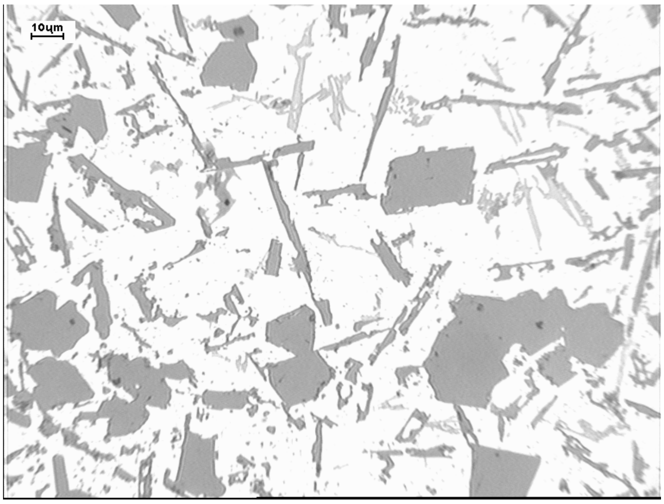


b)

Fig. 12. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 1.07% of AlCu19P1,4 and 0.02% of Fe

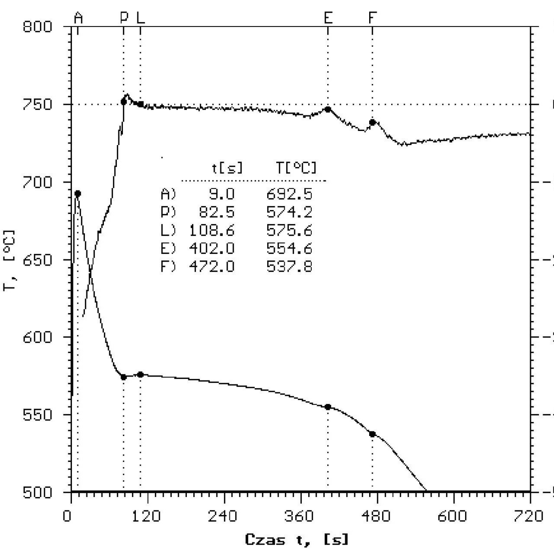
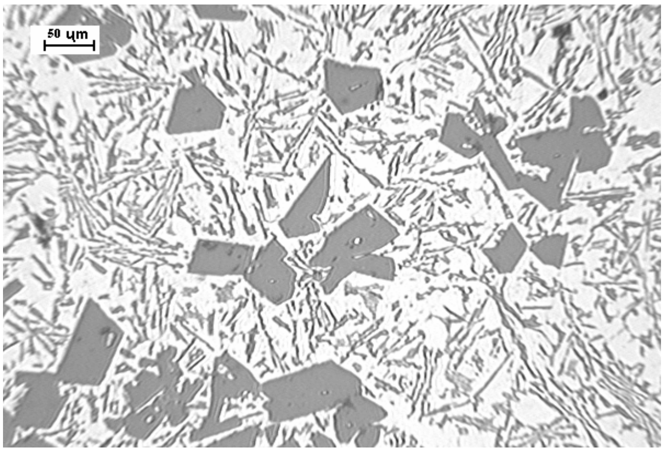


Fig. 13. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 0.12% of CuP12



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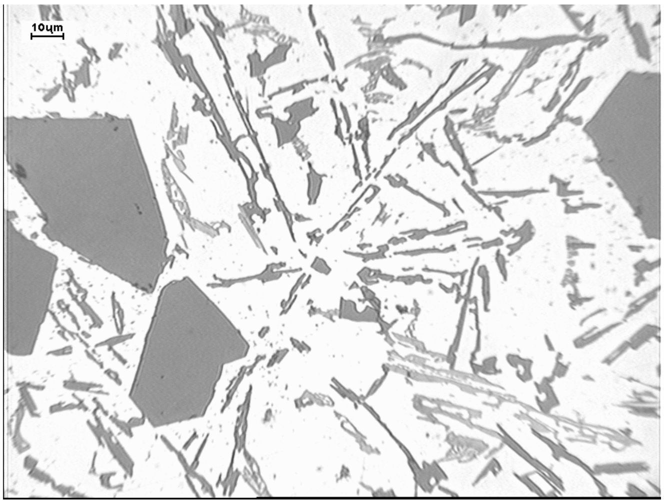


b)

Fig. 14. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 0.12% of CuP12

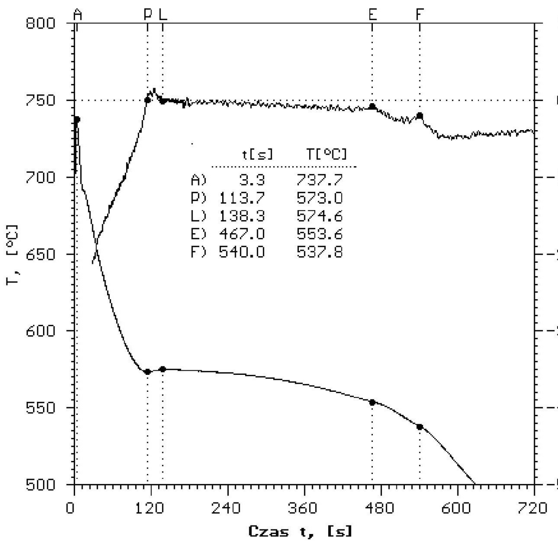
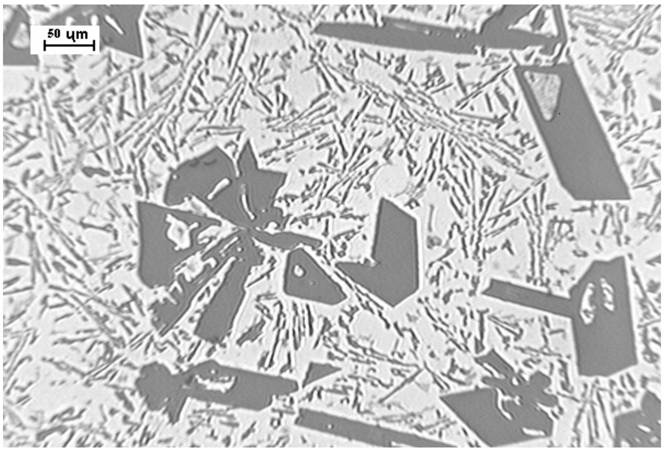


Fig. 15. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 0.12% of CuP12 and 0.02% of Fe



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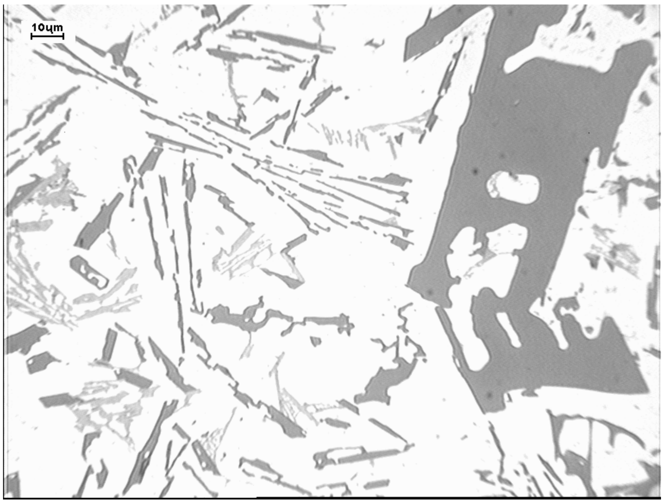


b)

Fig. 16. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 0.12% of CuP12 and 0.02% of Fe

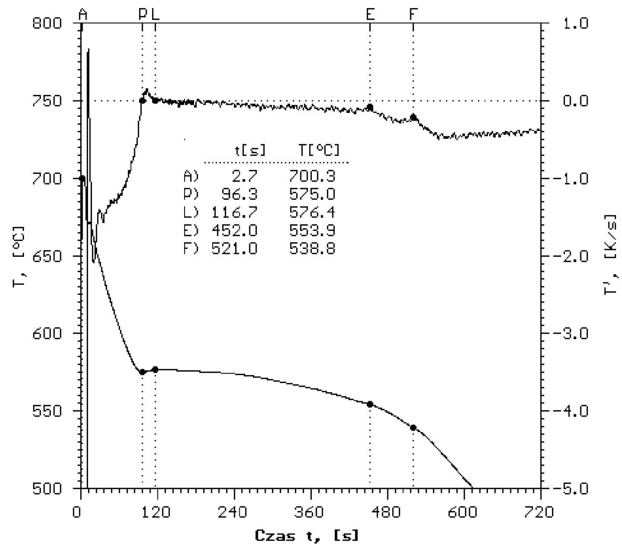
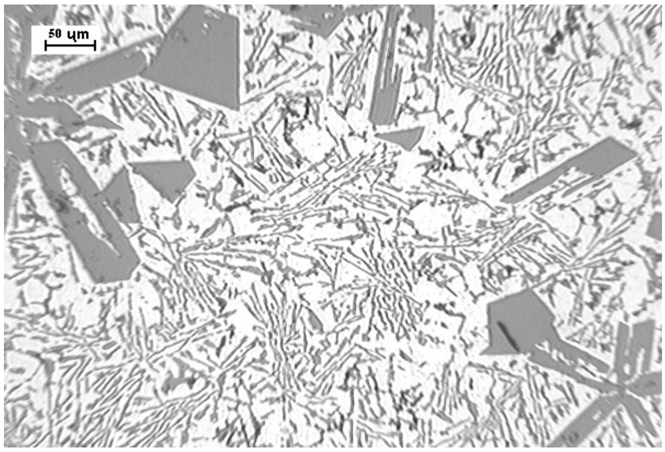


Fig. 17. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 0.12% of CuP12 and 0.01% of Fe



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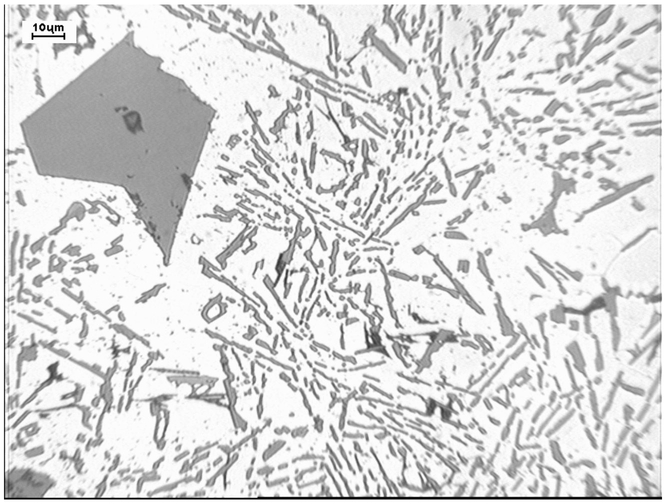

b)

Fig. 18. Diagram of Thermal-Derivation Analysis of hypereutectic silumin AlSi21CuNi modified with 0.12% of CuP12 and 0.01% of Fe

Metallographic studies of AlSi21CuNi silumin showed that the unmodified silumin (Fig. 2) was characterized by large primary silicon crystals with an average size of 114 µm and developed form. All modifying micro additions used in the study caused the refinement of the primary silicon crystals with a different effect (Table 1). Among the individual additives modifying the very good effect of the refinement of the primary silicon crystals was assured by the addition of AlCu19P1,4 (Fig. 4). The effect of the modification was improved with the use of this additive simultaneously with powdered iron (Fig. 12). Modification treatment of silumin with the addition of CuS (Figure 8) and the addition of CuP12 (Figure 14) proved to be less effective. Simultaneous modification with the addition of CuP12 and iron powder did not show clearly a better effect of silicon refinement (Figures 16 and 18).

4. Conclusions

Research on the modification of AlSi21CuNi piston silum proved that the phosphorus micro additive in the form of AlCu19P1,4 and CuP12 pre-alloys and sulfur in the form of CuS sulphide causes the refinement of primary silicon crystals. The use of phosphorus in the form of the AlCu19P1,4 pre-alloy provides a more advantageous effect of the refinement of the primary silicon crystals than the addition of phosphorus in the form of CuP12. The best effect of the refinement of the primary silicon crystals is ensured by the simultaneous modification of silumin with a phosphorus additive in AlCu19P1,4 in the amount of 1.07% and a simultaneous addition of 0.02% iron powder.

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改性对过共晶硅铝AlSi21CuNi中初生硅晶体细化的影响

關鍵詞
铝硅合金
微观结构
微添加剂
修改

摘要

本文研究了改性微量添加剂对过共晶AlSi21CuNi活塞硅铝中初生硅晶体细化的影响。作为改性剂，使用AlCu19P1.4和CuP12预合金形式的磷微量添加剂，CuS形式的硫和粉末形式的铁。改性微添加剂分开使用并一起使用。微量添加铁与磷一起使用。硫微量添加提供了初级硅晶体的碎裂，但不如磷微量添加剂有效。通过将AlCu19P1,4预合金形式的磷与粉末铁的微添加剂组合添加，可以确保初级硅晶体碎裂的最佳效果，从而将初级硅晶体的平均尺寸从114μm减小到20μm。