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(54) **ALUMINUM ALLOY, IN PARTICULAR FOR THE PRODUCTION OF MOULD SEGMENT
CASTINGS FOR FORMING TYRES, AND THE METHOD OF HEAT TREATMENT OF MOULD
SEGMENT CASTINGS.**

(57) The essence of the invention of an aluminium alloy which contains 85.55 to 89.00 % by mass of Al, 8.5 to 10.00 % by mass of Si, 0.6 to 1.2 % by mass of Cu, 0.6 to 1.0 % by mass of Ni, 0.4 to 0.8% by mass of Mn, 0.03 to 0.05 % by mass of Sr, max. 0.4% by mass of Mg, max. 0.6 % by mass of Fe, max. 0.1 % by mass of Ti, max. 0.1 % by mass of Zn and max. 0.05 % by mass of other additives separately, with the total share of other

additives being 0.15 % by mass at the maximum. Another essence of the invention is a method of heat treatment of mould segment castings, wherein the mould segment castings are heated to an annealing temperature of 520 °C and annealed for 0.5 to 8 hours, after which they are cooled in water at a temperature of 50 to 60 °C and then subjected to ageing at a temperature of 170 °C for 6 to 8 hours.

EP 3 124 632 A1

DescriptionTechnical field

5 **[0001]** The invention concerns a newly developed aluminium alloy containing other alloying elements, in particular for the production of mould segment castings for pressing tyres for motor vehicles in the automotive industry.

State of the art

10 **[0002]** Currently, aluminium alloys of the Al - Mg and Al - Si type are used for the production of metal moulds designed for tyre production. The mould itself is composed of 8 to 36 segments, depending on the dimensions of the manufactured tyre. The functional area of the mould itself is machined to the desired shape and dimensions by milling, turning and drilling. The functional area of the mould is then treated with a coating of nanolayers in order to extend the time without cleaning the area and to extend the life of the mould.

15 **[0003]** The segment casting process is carried out using the low pressure casting technology, with the melt being kept at the casting temperature in a holding furnace for the entire period of casting. The time between the first and the last casting process is about 4 hours, which brings with it a requirement for time stability of the melted alloy.

[0004] The tyres as such are manufactured by vulcanization of a mixture of organic substances at higher temperatures - 150 to 170 °C, but also at up to 220 °C. Thanks to the working temperature of the mould, is the alloy of the mould is required to possess stable mechanical properties under normal and increased temperature.

20 **[0005]** A significant disadvantage of the known aluminium alloys is that their mechanical properties decline very significantly at temperatures over 100 °C. Their mechanical properties can be increased by alloying them using suitable elements in combination with heat treatment with optimum parameters.

25 Essence of invention

[0006] The deficiencies mentioned above are, to a large extent, eliminated by an aluminium alloy, in particular for the production of mould segment castings for forming tyres for motor vehicles in the automotive industry, according to this invention. Its essence is that the alloy contains 85.55 to 89.00 % by mass of Al, 8.5 to 10.00 % by mass of Si, 0.6 to 1.2
30 % by mass of Cu, 0.6 to 1.0% by mass of Ni, 0.4 to 0.8 % by mass of Mn, 0.03 to 0.05 % by mass of Sr, max. 0.4 % by mass of Mg, max. 0.6 % by mass of Fe, max. 0.1 % by mass of Ti, max. 0.1 % by mass of Zn and max. 0.05 % by mass of other additives separately, with the total share of other additives being 0.15 % by mass at the maximum.

[0007] Another subject of the invention is a method of heat treatment of mould segment castings, wherein the mould segment castings are heated to an annealing temperature of 520 °C and annealed for 0.5 to 8 hours, after which they
35 are cooled in water at a temperature of 50 to 60 °C and then subjected to ageing at a temperature of 170 °C for 6 to 8 hours.

[0008] This invention introduces a newly developed aluminium alloy in the mould production technology using low-pressure casting; thanks to the suggested heat treatment process, this alloy ensures stability of mechanical properties even at elevated temperatures. The invented chemical composition of the alloy in combination with heat treatment results in an increased tensile strength compared to the currently used alloys of the Al-Si type - by 26 % at a temperature of 20
40 °C, by 30 % at a temperature of 170 °C and, compared to Al-Mg type alloys, by 49 % at a temperature of 20 °C and by 59 % at a temperature of 170 °C.

[0009] The essence of the invention is the suggested chemical composition of the newly developed Al-Si-Cu type alloy which guarantees high mechanical properties of the alloy for both normal and elevated temperatures thanks to the optimum content of alloying elements, together with the suggested heat treatment process. The new alloy
45 AlSi10CuNiMnSr with the chemical composition according to the present invention has high mechanical properties at normal and elevated temperatures of up to 250 °C.

[0010] The invention has been developed with a view to applying the new alloy in mould segment castings for the production of tyres where the mechanical properties are required to be stable even at elevated temperatures. Another requirement was the stability of mechanical properties of castings cast at the beginning and at the end of the casting
50 process.

[0011] Based on the knowledge of the influence of various alloying elements on the mechanical properties of Al-Si alloys, the invented alloy is alloyed with the following elements. Silicon - main alloying element which significantly influences the casting properties - fluidity, and creates an intermetallic phase of Mg_2Si , which enables the alloy to be hardened, together with an addition of Mg. Copper - alloyed in order to increase the strength properties by curing thanks
55 to the formation of an intermetallic phase of $CuAl_2$. Nickel - alloyed in order to increase the strength properties at higher temperatures and create a hardening phase of Al_6Cu_3Ni , reduce the thermal expansion coefficient and corrosion resistance. Manganese - the purpose of alloying is to increase the strength properties, raise the temperature of recrystallization, refine the grain, suppress the negative effects of elimination of iron in a laminar form and create an intermetallic phase

of α -AlFeMnSi. Strontium - applied to modify the separated particles of eutectic silicon. Elimination of Mg in the alloy.

Clarification of drawings

[0012] The aluminium alloy, in particular for the production of mould segment castings for forming tyres for motor vehicles in the automotive industry, and the method of heat treatment of these castings will be described in greater detail on a specific embodiment using the attached drawings, where Fig. 1 shows the microstructure of the inventive alloy. Fig. 2 shows the intermetallic phases of α -AlFeMnSi. Fig. 3 depicts the site of spot EDS analysis. Fig. 4 shows the polycomponent intermetallic phase with an increased Ni content. Fig. 5 shows the chemical spectrum of the detected elements of the polycomponent intermetallic phase with an increased Ni content.

Embodiments of the invention

[0013] The embodiment of the aluminium alloy for the production of mould segment castings for forming tyres for motor vehicles in the automotive industry contains 85.55 to 89.00 % by mass of Al, 8.5 to 10.00 % by mass of Si, 0.6 to 1.2 % by mass of Cu, 0.6 to 1.0 % by mass of Ni, 0.4 to 0.8 % by mass of Mn, 0.03 to 0.05 % by mass of Sr, max. 0.4 % by mass of Mg, max. 0.6 % by mass of Fe, max. 0.1 % by mass of Ti, max. 0.1 % by mass of Zn and max. 0.05 % by mass of other additives separately, with the total share of other additives being 0.15 % by mass at the maximum. The alloy is modified without TiB vaccination.

[0014] To increase the mechanical properties, it is necessary to subject the castings from the invented alloy to heat treatment. The heat treatment process consists of a solution annealing process at a temperature of 520 °C, where the castings are loaded into the furnace at the ambient temperature and reach the annealing temperature together with the working space of the furnace. The holding time at the annealing temperature depends on the wall thickness of the casting. This is followed by cooling in water at a temperature of 50-60 °C, depending on the dimensions and shape of the casting. The last step in the heat treatment process is artificial ageing at a temperature of 170 °C; once again, the duration of this process is dependent on the dimensions of the casting. All parameters of the individual steps are summarized in Tab. 1.

Tab. 1 Parameters of heat treatment of the invented alloy

Process	Parameters	Note
Solution annealing	520 °C/ 0.5 to 8 h	based on casting wall thickness (up to 12 mm - 45 min.; 100mm-6 to 8h)
Cooling in water	50 to 60 °C	based on wall thickness and shape of the casting
Artificial ageing	170°C/6 to 8h	based on wall thickness of the casting

[0015] The mechanical properties of the invented alloy were tested by static tensile tests and Brinell hardness measurement on samples made from mould segments after heat treatment as well as without any heat treatment.

[0016] The average values of tensile strength and elongation of the invented alloy without any heat treatment and after heat treatment, recorded in the static tensile test, are recorded in Tab. 2. The static test was carried out at a temperature of 20 °C. When comparing the measured values, there is a noticeable increase in tensile strength by 80 % and of elongation by 21 % as a result of the heat treatment process.

Tab. 2 Mechanical properties of invented alloy before and after heat treatment

Condition of samples	R _m [MPa]	A [%]
Samples without heat treatment	143.5	4.8
Samples after heat treatment	258.3	5.8

[0017] Another step in the process of identifying mechanical properties, i.e. yield strength and elongation, was a static tensile test at different temperatures. The temperatures of 20, 170 - mould working temperature - and 250 °C were selected for the testing. The test samples were heat treated. The results of the static tensile test - average values at different temperatures - are recorded in Tab. 3. When comparing the strength limit of the invented alloy at the individual test temperatures, there is no noticeable difference. Thanks to the elevated temperature of the test carried out at a temperature of 250 °C, material elongation was increased by 37 % compared to the test carried out at a temperature of

20 °C.

Tab. 3 Mechanical properties of the invented alloy at different temperatures

Temperature [°C]	R _m [MPa]	A [%]
20	291.8	5.4
170	290.5	5.8
250	299.5	7.4

[0018] Another test aimed at investigating the mechanical properties of the invented alloy was the Brinell hardness test, which was carried out on samples without heat treatment and after heat treatment. The test was carried out at a temperature of 20 °C. The average values of Brinell hardness are recorded in Tab. 4. When comparing the values, it is obvious that the heat treatment process resulted in an increase in the hardness of the invented alloy by 90 %

Tab. 4 Brinell hardness of the alloy before and after heat treatment

Condition of samples	Brinell hardness [HB ₁₀]
Samples without heat treatment	76.3
Samples after heat treatment	144.8

[0019] Fig. 1 shows the microstructure of the invented alloy. It is formed by α -phase dendritic cells and by a eutectic mixture consisting of particles of separated eutectic silicon and the addition of strontium in the melt, as a modifier. Fig. 2 shows an image of the intermetallic phase of α -AlFeMnSi taken by a scanning electron microscope. Subsequently, a spot EDS analysis was also performed on this phase. The site of the analysis is shown in Fig. 3.

[0020] The subsequent quantification of the content of individual elements is recorded in Tab. 5.

Tab. 5. Quantification of the results of EDS analysis of the intermetallic phase of α -AlFeMnSi

Element	Series	Unn. [wt. %]	C norm. [wt. %]	C Atom. [at. %]	C error (3sigma) [wt. %]
Aluminium	K-series	50.78	59.38	71.53	7.73
Silicon	K-series	6.95	8.13	9.41	1.06
Manganese	K-series	14.00	16.38	9.69	1.19
Iron	K-series	13.78	16.11	9.38	1.16
	Total:	85.51	100	100	

[0021] A polycomponent intermetallic phase with an increased content of nickel is created by adding nickel in the invented alloy - Fig. 4.

[0022] A spot EDS analysis was carried out on the recognized intermetallic phase to determine its chemical composition. The site of the analysis is shown in Fig. 5. It is an intermetallic phase of Al₆Cu₃Ni.

Tab. 6 Quantification of the results of spot EDS analysis of the polycomponent intermetallic phase with an increased Ni content.

Element	Series	Unn. [wt. %]	C norm. [wt. %]	C Atom. [at. %]	C error (3sigma) [wt. %]
Manganese	K-series	0.95	0.99	0.59	0.18
Aluminium	K-series	58.39	61.15	74.04	8.88
Iron	K-series	4.82	5.05	2.95	0.48
Silicon	K-series	4.92	5.15	5.99	0.79
Nickel	K-series	20.56	21.53	11.6	1.65
Copper	K-series	4.38	4.59	2.36	0.46

(continued)

Element	Series	Unn. [wt. %]	C norm. [wt. %]	C Atom. [at. %]	C error (3sigma) [wt. %]
Magnesium	K-series	1.48	1.55	2.08	0.38
	Total:	95.49	100.00	100.00	

Industrial use

[0023] The aluminium alloy according to the present invention can be particularly used in the production of mould segment castings for forming tyres for motor vehicles in the automotive industry.

Claims

1. An aluminium alloy, in particular for the production of a mould segment castings for forming tyres for motor vehicles in the automotive industry, **characterized in that** it contains 85.55 to 89.00 % by mass of Al, 8.5 to 10.00 % by mass of Si, 0.6 to 1.2 % by mass of Cu, 0.6 to 1.0 % by mass of Ni, 0.4 to 0.8 % by mass of Mn, 0.03 to 0.05 % by mass of Sr, max. 0.4 % by mass of Mg, max. 0.6 % by mass of Fe, max. 0.1 % by mass of Ti, max. 0.1 % by mass of Zn and max. 0.05 % by mass of other additives separately, with the total share of other additives being 0.15 % by mass at the maximum.
2. A method of heat treatment of the mould segment castings from the aluminium alloy as in Claim 1, **wherein** the mould segment castings are heated to an annealing temperature of 520 °C and annealed for 0.5 to 8 hours, after which they are cooled in water at a temperature of 50 to 60 °C and then subjected to ageing at a temperature of 170 °C for 6 to 8 hours.

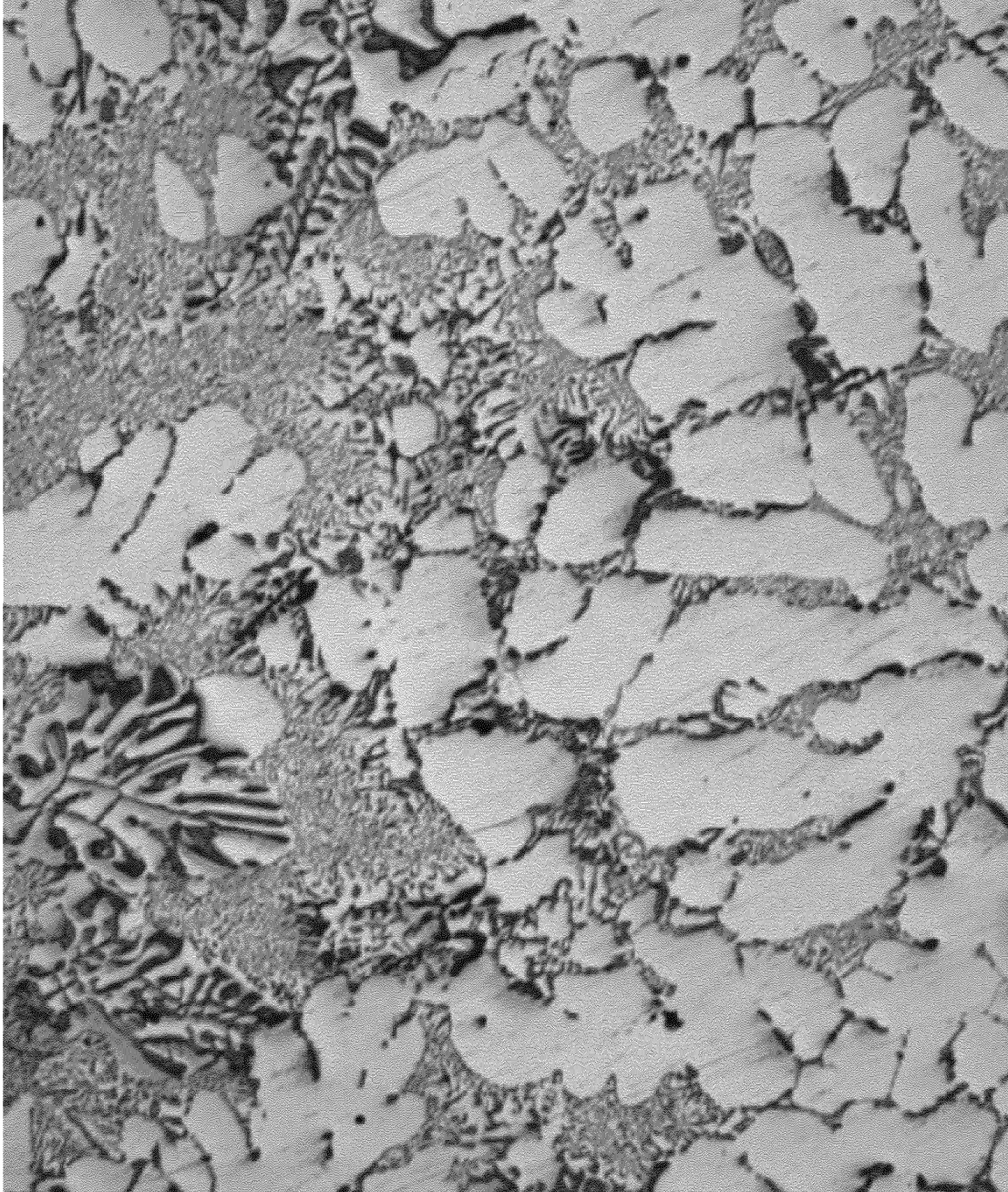


Fig. 1

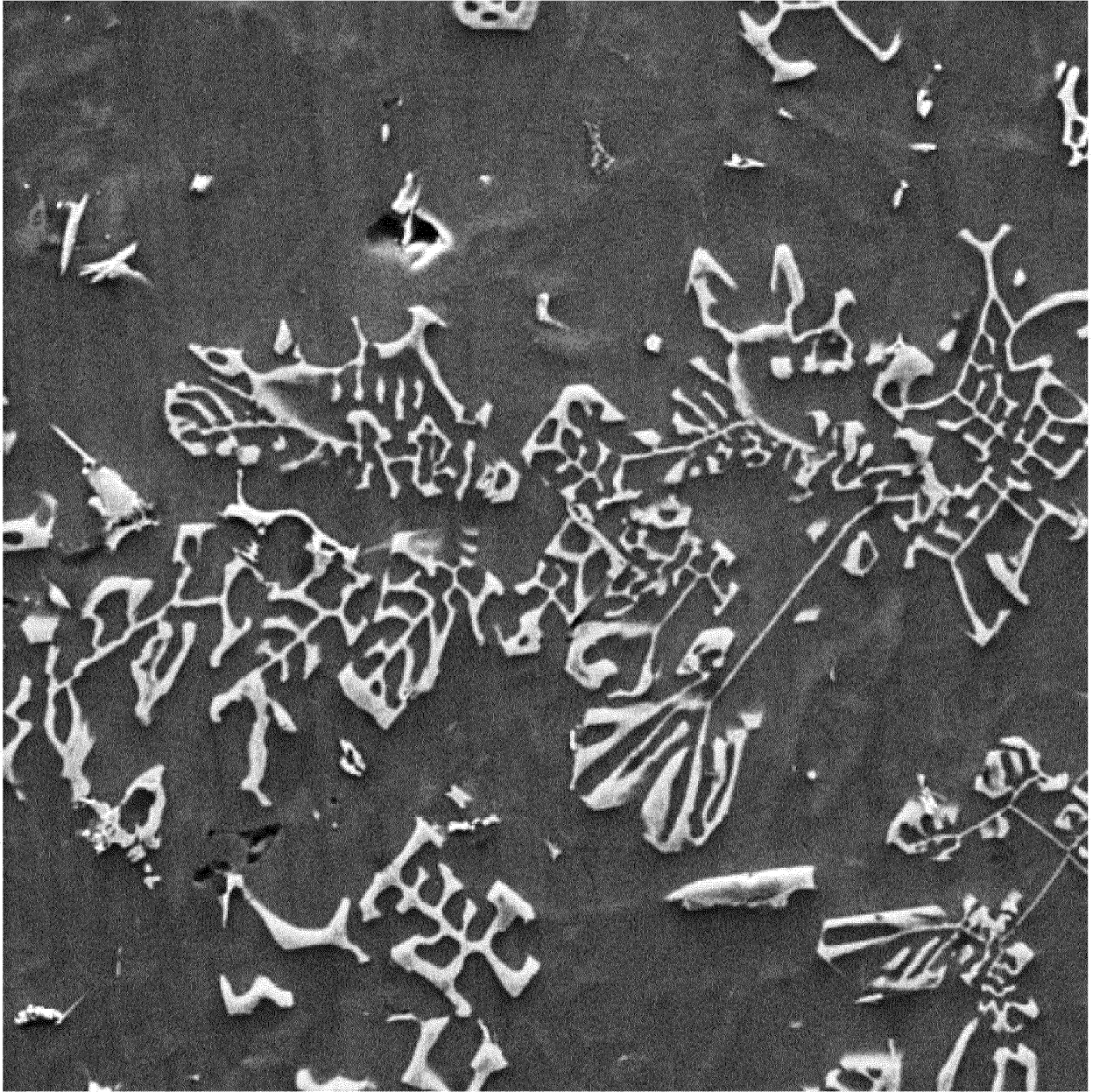


Fig. 2

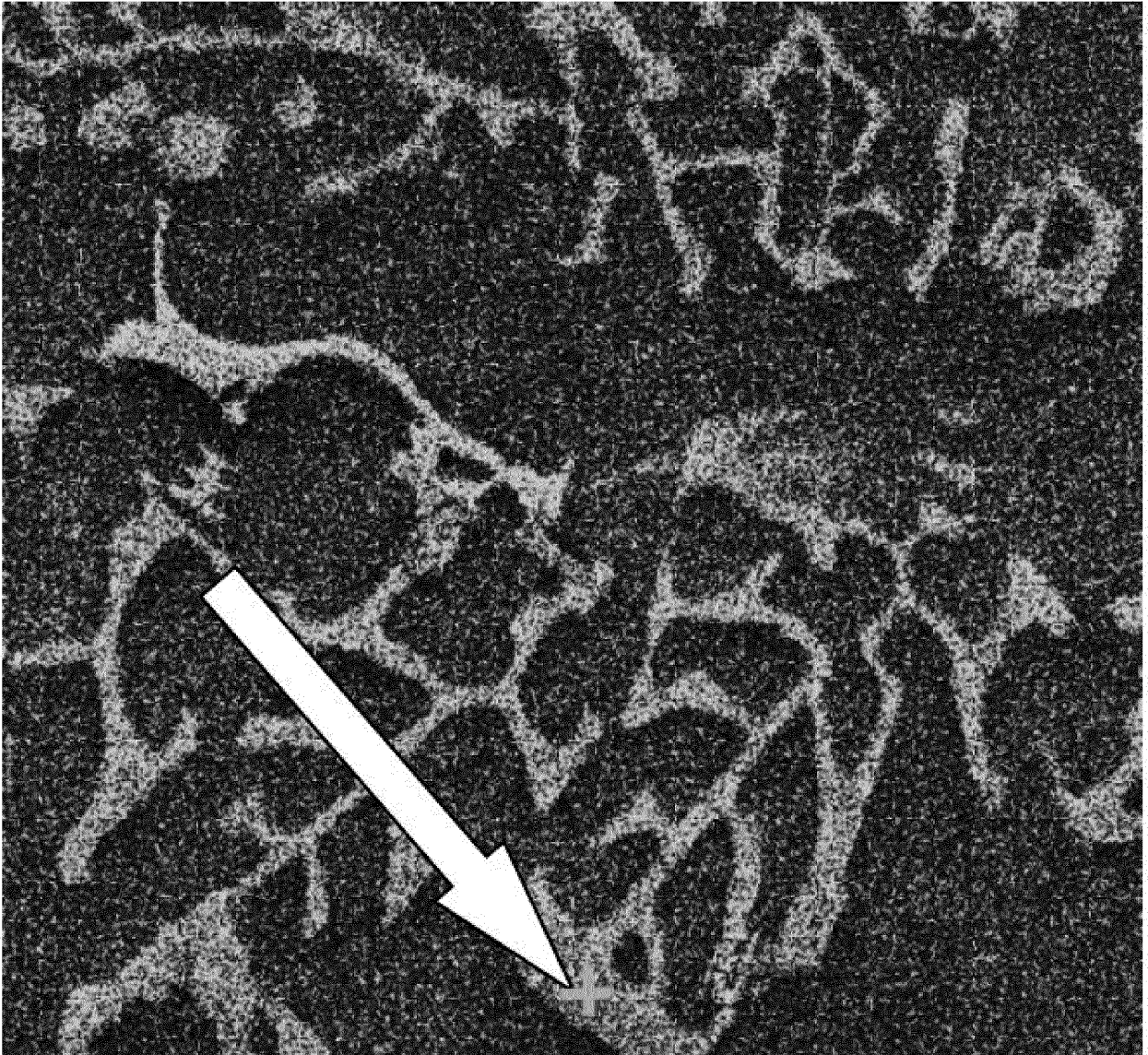


Fig. 3



Fig. 4

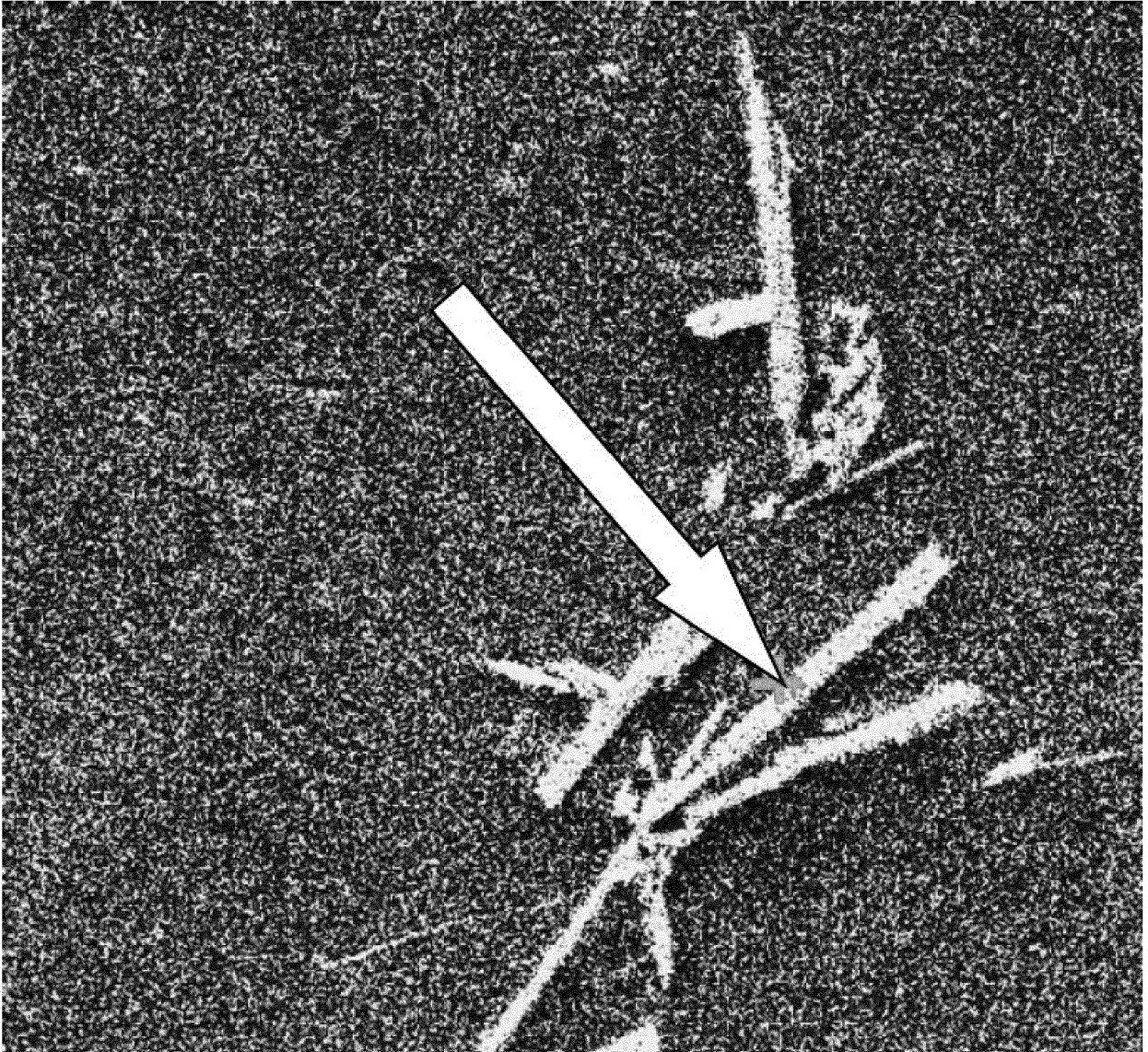


Fig. 5



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 Application Number
 EP 16 18 1626

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 9 December 2016	Examiner González Junquera, J
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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