FORMING OF TECHNOLOGICAL AND MECHANICAL PROPERTIES OF CASTED ALUMINIUM MACHINE PARTS

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Summary

A method of research and obtained results that concern an effect of applied purifying processes on the variations of technological and mechanical properties, were described in this paper. The carried-out processes of purifying by the refining and modifying as well as the filtration and heat treatment, have affected the kinetics of crystallization process and structure and led to the improvement of mechanical properties (R_m, A_5 and *KCV*) and the decrease in the porosity of aluminum alloys. The original research concerning the impact spark ability has proved the possibility to obtain adequately purified castings that can be applied in conditions of explosive threat. The applied processes of purifying by the modification and filtration and heat treatment allow to obtain from the charges materials of low quality, the aluminum castings of adequate high mechanical and technological properties that satisfy the buyers' requirements.

Keywords: aluminum alloys, purifying, sparking, machinability, porosity

Kształtowanie właściwości mechanicznych i technologicznych odlewanych aluminiowych części maszyn

Streszczenie

W artykule przedstawiono metodykę badań i otrzymane wyniki dotyczące wpływu zastosowanych procesów uszlachetniania na zmiany właściwości mechanicznych i technologicznych. Przeprowadzone procesy uszlachetniania, poprzez rafinację i modyfikację oraz filtrację i obróbkę cieplną, wpłynęły na zmianę kinetyki procesów krystalizacji, struktury, a przez to na poprawę właściwości mechanicznych (R_m, A_5 i *KCV*) i zmniejszenie porowatości stopów aluminium. Wykonane oryginalne badania dotyczące skłonności do iskrzenia udarowego wykazały możliwość otrzymywania odlewów odpowiednio uszlachetnionych, które mogą być stosowane w warunkach zagrożenia wybuchowego. Zastosowane procesy uszlachetniania, poprzez modyfikację i filtracje oraz obróbkę cieplną, pozwalają na uzyskanie z materiałów wsadowych o niskiej jakości odlewów aluminiowych o odpowiednio wysokich właściwościach mechanicznych i technologicznych, spełniających wymagania stawiane przez odbiorców.

Słowa kluczowe: stopy aluminium, uszlachetnianie, iskrzenie, skrawalność, porowatość

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1. Introduction

Obtaining of adequate changes in the structure of casted mechanical parts has a very significant effect on their mechanical and technological properties [1]. It can be carried out by intended influence of appropriately applied processes, such as:

- solidification and crystallization;
- filtration;
- heat treatment.

Adequate metallurgical operations of refining and modification are at present the most effective methods in the foundry industry to obtain the best structure of manufactured castings. In aluminum alloys and first of all in the silumins, the structure consists mainly of two basic phases. These phases are: the plastic matrix generated from the solid solution (mixed crystals) α on the aluminum basis and hard, brittle silicon crystals. Mechanical properties of these alloys depend first of all on the grade of „branching" and morphology variation of silicon Si crystals that were obtained as results of applied purifying processes and heat treatment.

The structure density („structure tightness") is a very important technological property that refers to inter alia, automobiles castings. The gas and shrinkage porosity as well as oxide impurities should not be developed in the structure of manufactured castings. In connection with high requirements for the casted metal parts it is necessary to obtain the castings that are characterized by possible least grade of impurity. Application of filtration processes (by ceramic filters) during the teeming (casting) of liquid alloy in the sand or metal moulds, ensures the possibility to obtain the castings of high quality [2, 3, 4].

The heat treatment belongs to the end processes of the forming of technological and mechanical properties of the castings obtained. For the aluminum alloys the heat treatment consists in the increase of their strength. The processes of heat treatment apply most often the operations of super saturation and ageing (artificial or natural) which are designated by symbol T6 [5]. The possibility of fast start in the castings production, mostly in the technology BAT (most available technology) has led to the wide application of casted machine parts in many branches of industry. Hence, an important problem is to acquire the adequate knowledge that concerns the application of design materials in the places threatened with explosion. The possibility of such explosion threats is caused, inter alia, by the impact sparking of casted machine parts [6].

Casted aluminum alloys as compared to the ferroalloys and copper alloys are characterized by significantly low machineability. Better machinability can be obtained by application of alloys components, such as copper as well as by the processes of purifying. Both operations restrict, so called „smearing of alloy" during machining. Adequate application of the purifying processes of aluminum alloys that are poured into the sand and metal moulds, allows to obtain high mechanical properties and required technological ones that satisfy the requirements of designers and users of manufactured castings.

2. Methodology and results of investigation

The alloys from the metallurgy processing: EN AC – AlSi9Mg (AK9) and EN AC – AlSi11 (AK11) and the automobile alloy EN AC – AlSi9Cu1Mg (AS9C) were analysed. The investigated alloys AK9 and AK11 during melting in the resistance furnace, were purified by metallurgic operations such as a refining by means of hexachloroethane and modification by master alloy of strontium or antimonium. After the processes of refining and modification the filtration of investigated alloys by foam filters during pouring to the metal mould was carried-out.

For the automobile alloy AS9C the purifying of structure by application of heat treatment – super saturation and artificial ageing (T6) was applied. Simultaneously to the investigation of crystallization processes of alloys AK9 and AK11, by the method of Thermo-Derivation Analysis and Electro-Derivation (ATD-AED) [1, 7], the specimens moulded for the investigation of mechanical properties (R_m, A_5, HB, KCV), chemical composition and the heat treatment were obtained by purifying.

The graphic record according to the method ATD-AED shown in Fig.1, gives the crystallization curve versus time; thermal – $t = f(\tau)$ and $dt/d\tau = f(\tau)$ as well as electrical – $\sigma = f(\tau)$ and $d\sigma/d\tau = f(\tau)$. Registered thermal and electrical effects (peaks) present the kinetics of crystallization of single phases that create the casting structure after applied processes of purifying.

Metallographic investigation was made to verify the variations that occur in the profiles of crystallization curves registered by method ATD-AED and obtained after the purifying processes. This investigation was carried-out on the electron microscope. The metallographic specimens deeply etched and cut from the grip parts of strength specimens were prepared for the metallographic analysis. First of all, the microstructure investigation of alloys that were directly casted from the pig sows were made with the aim to evaluate the effectiveness of the processes that have to be carried out during the next stages of investigation. In the Fig. 2 is presented the inside faults in the shape of gas and oxides porosities occurring in the AK11 alloy directly melted from the pig sows.

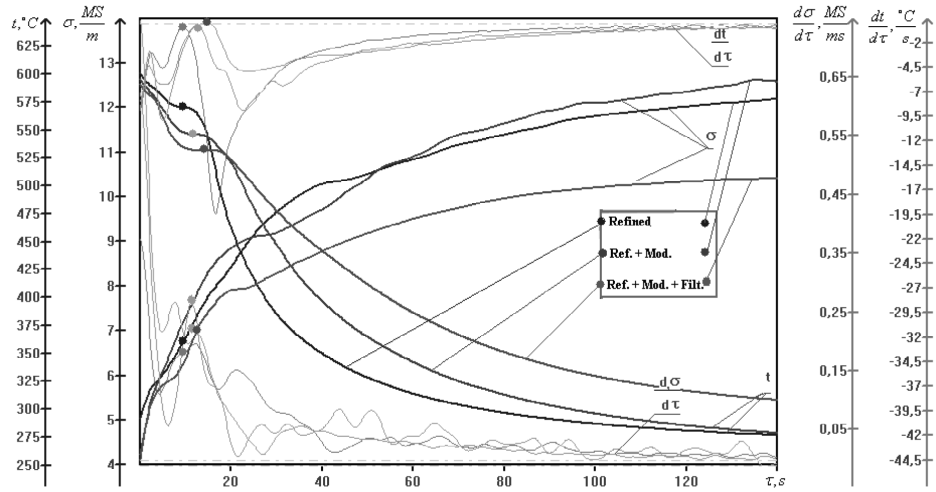
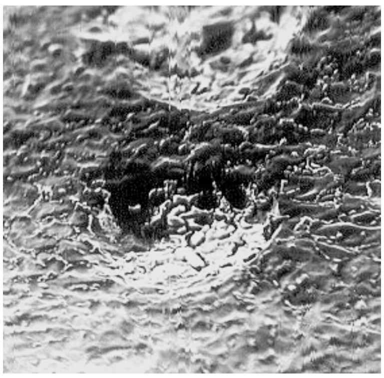


Fig. 1. Graphic record by the method ATD-AED curves of crystallization of alloy AK9 after the metallurgic treatments

a)



b)

Fig. 2. Inside faults of microstructure of AK11 alloy directly melted from the pig sows: a) gas porosity (bubbles), b) shrinking-gas porosity and membrane of oxides

The microstructures of non-purified alloy that was directly casted from the pig sows indicate its dissatisfying quality. The processes of refining and modifications that were registered graphically – according to method ATD-AED differ from one another by the shape of crystallization curves. These differences were confirmed by the morphology changes of obtained scanned microstructures. An effect of applied melting processes (purifying) of AK11 alloy on the structure changes is presented in Fig. 3.

a)

b)

c)

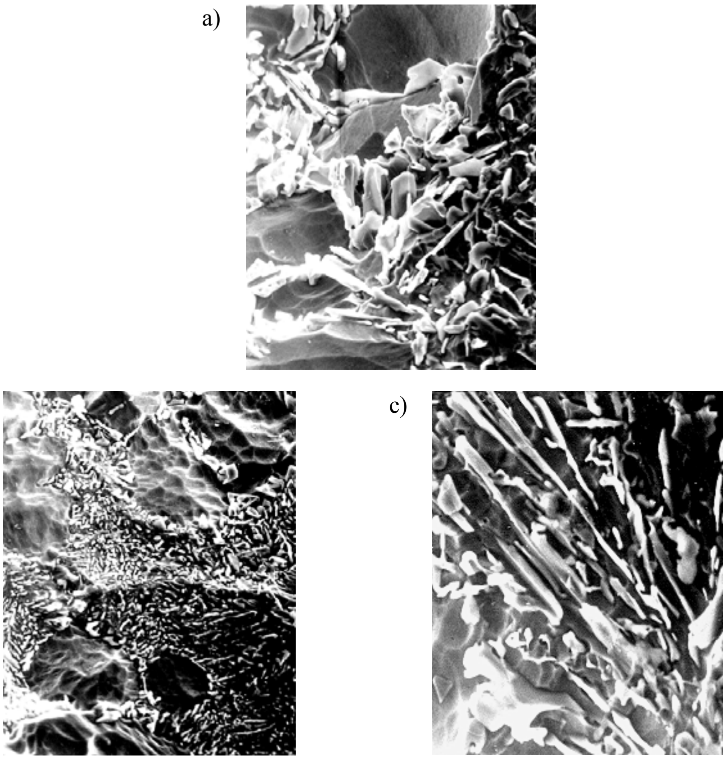


Fig. 3. Microstructures of AK11 alloy: a) refined alloy, b) alloy refined and modified by strontium, c) alloy refined and modified by antymonium

The microstructure of AK11 alloy (Fig. 3a) after refining by hexachloroethan is non-purified. In the interdendritic spaces of α phase the coarse-grained eutectic $\alpha + Si$ was crystallized. Very coarse-grained separations of eutectic silicon can be observed. The form of eutectic silicon was changes by the applied strontium or antimonium modification. After the strontium modification the purified eutectic $\alpha + Si$ with very tiny separations of eutectic silicon was obtained (Fig. 3b). However, the antimonium modification has caused the crystallization of purified „striped" eutectic $\alpha + Si$ with lamellar separations of eutectic silicon (Fig. 3c).

The main task of filtration processes is the separation of solid substances from the liquid ones. It allows gaining the purifying of alloys in the liquid state on the stage of filling (pouring into) sand and metal moulds. The ceramic filters of determined porosity placed in the gating system of metal mould have caused, as result of adequate flow mechanism, sedimentation and separation of impurities contained in the alloy. Original results of investigation introduce the microstructures that were obtained after pouring into the foam filters the alloys after filtration processes. Microstructures in Fig. 4 show the shape and arrangement of the impurities held inside of poured filter.

The verification of the effect of forming the mechanical properties were the measurements of the changes of tensile strength R_m, unit elongation A_5, hardness *HB* and impact strength *KCV,* after the processes of purifying. Investigation of mechanical properties was carried-out in the metal moulds according to polish standard PN-82/H-88002.

Casting of specimens with the application of filtration processes was carried-out according to the standard that was mentioned above, however with the mounted ceramic filter in the gating system of metal mould. A significant increase in the mechanical properties (R_m, A_5 and *KCV*) as compared to the no purified aluminum alloys, has confirmed the favorable changes in the kinetics processes of crystallization that were registered by the method ATD-AED (Fig. 1) and morphology of obtained microstructures (Fig. 3).

The positive influence of purifying, modifying and filtration processes as well as the heat treatment were confirmed by very great increase in the mechanical properties of investigated aluminum alloys. Comparison of mechanical properties of investigated alloys after the processes of purifying is given in form of column diagrams in Fig. 4 and Fig. 5.

a) b)

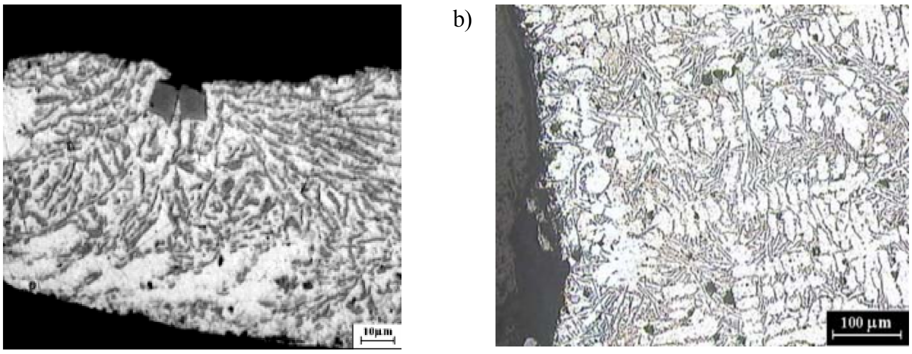


Fig. 4. Microstructure of filters poured with the alloys melted from the pig sows: a) impurities held in the AK11 alloy, b) impurities held in the AK9

Automobile alloy AlSi9Cu1Mg after super saturation and artificial ageing, according to the heat treatment (T6), was consolidated by separation, giving significant increase in the tensile strength R_m and hardness *HB* as compared to the alloy without heat treatment (Fig. 6). The next stage of investigation has concerned the forming of technological properties after the carried-out processes of purifying. The carried-out processes of purifying and modifying have become noticeable during the investigation of the porosity of the aluminum alloys.

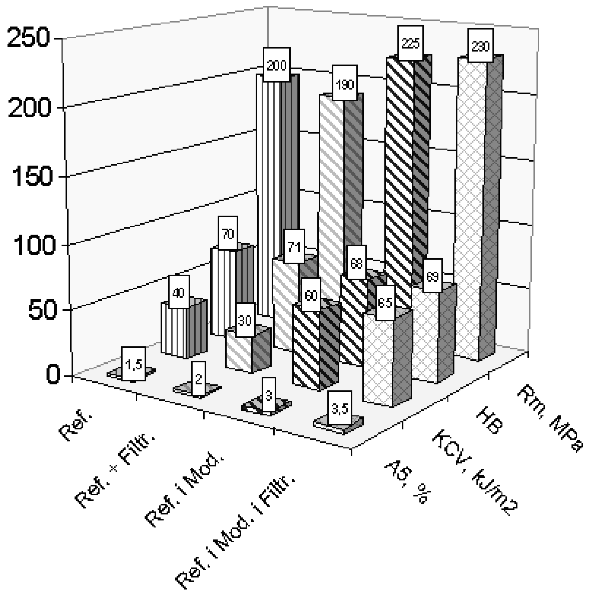


Fig. 5. Comparison of mechanical properties of alloy AK11

The porosity investigation of casted aluminum alloys was carried-out on the casting geometer GL [4]. The metallic or ceramic pots were used for the determination of solidifying velocity in the metal mould or in the sand form on the arrangement and shape of developed porosity of investigated alloys. The casted specimens were cut in the longitudinal plane. The metallographic specimens were prepared. The results that were obtained from the investigation of the porosity were presented on the longitudinal cross-sections of casted specimens and shown in Fig. 7 and Fig. 8.

The view of the porosity obtained and the shapes of specimens indicate the very significant effect of cooling speed on the shrinkage of investigated alloy that is illustrated by the generated concave meniscus. Strontium modification as compared to the non-modified alloys has a positive effect on the decrease in their porosity (Fig. 7b and 8b).

Investigation of machine-ability (Fig. 9) was made on the specimens of alloy AK9 that were cut out from the poured samplers by the method ATD-AED after the purifying process. The obtained results of machinability investigation are shown in Fig. 10. The original results of the investigation of technological properties that were obtained on the test rig (Fig. 11) concerned the impact sparking ability of aluminum alloys.

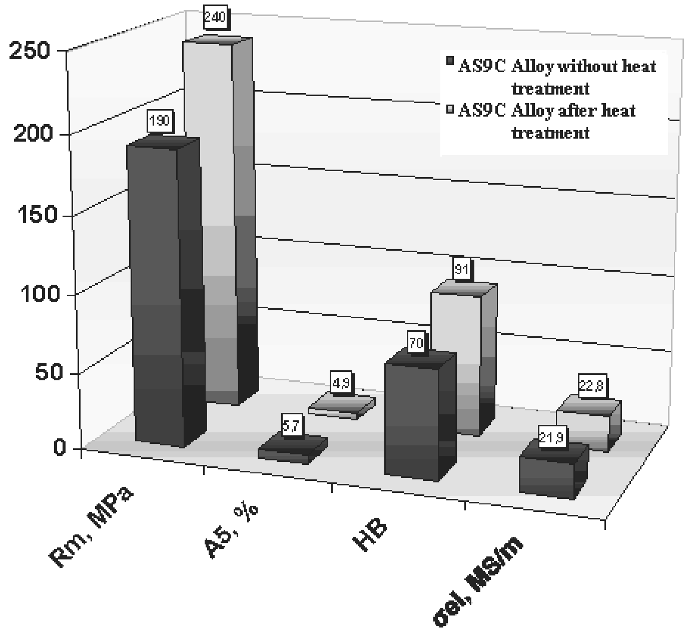


Fig. 6. Comparison of mechanical properties and electrical conductivity of AS9C1 alloy without and after heat treatment

a) b)

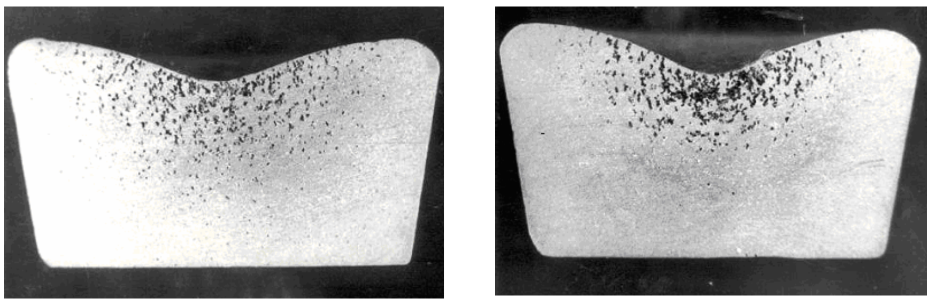


Fig. 7. General view of specimen shape and the arrangement of porosities of AK9 alloy AK9 poured to the metal melting pot: a) non-purified alloy, b) purified, modified and filtered alloy

a) b)

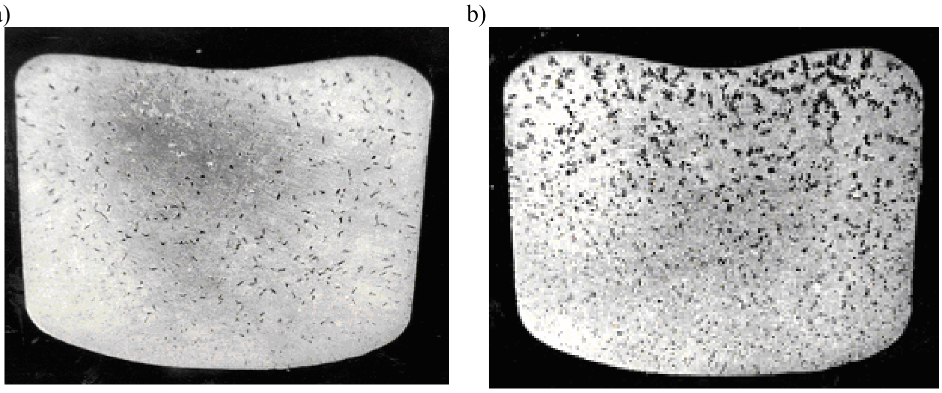


Fig. 8. View of the specimen and the arrangement of AK9 alloy porosity poured to the ceramic melting pot: a) non-purified alloy, b) purified, modified and filtered alloy

a)

b)

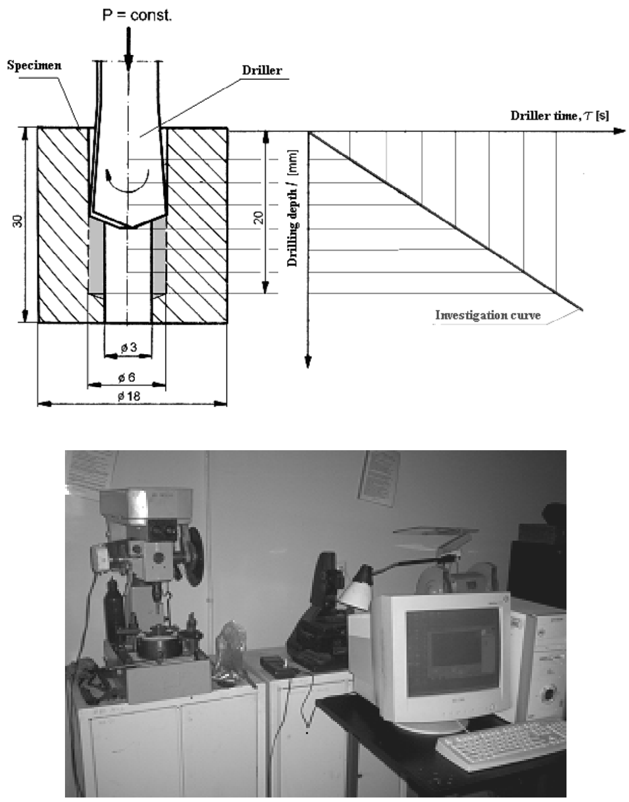


Fig. 9. Test rig for the investigation of machine-ability by the method of reboring:
a) lay-out of the reboring method, b) general view of the test rig with the measuring system

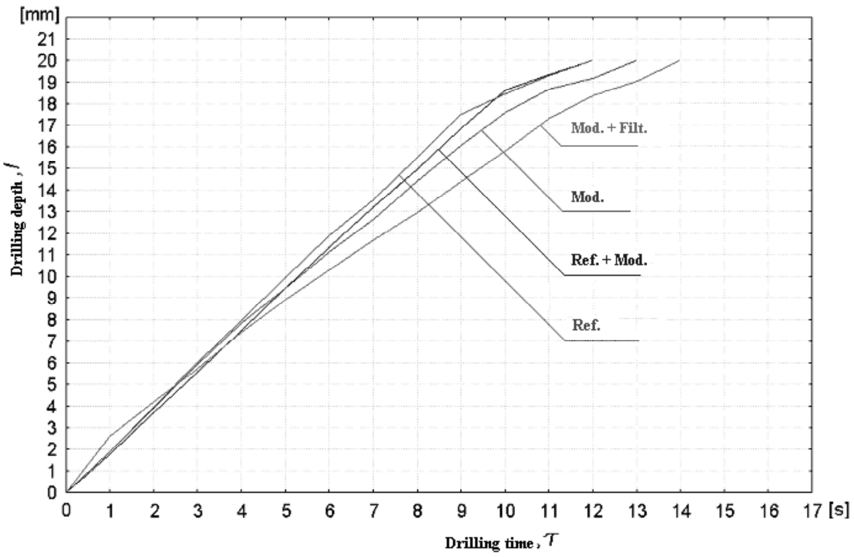


Fig. 10. Comparison of mean curves of machine-ability of alloy AK9
after the applied processes of purifying

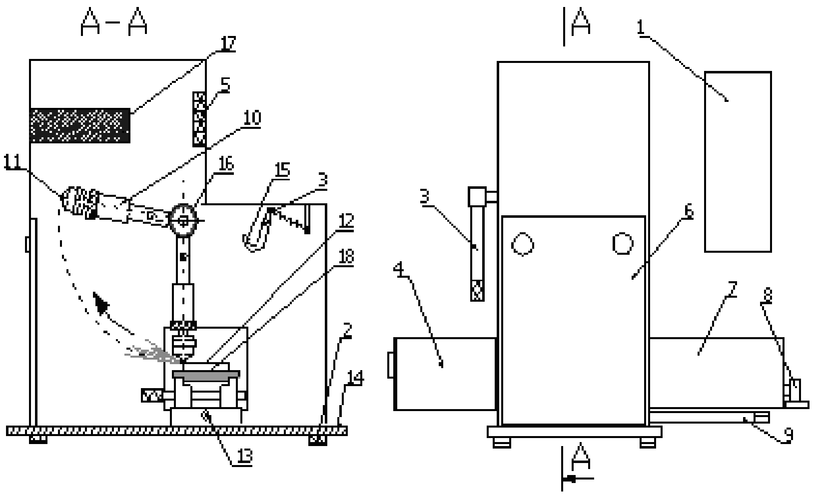


Fig. 11. Lay-out of the test rig for the investigation of the impact sparking: 1 – computer, 2 – rubber washers, 3 – mechanism releasing the spark striker, 4 – video-camera, 5 – bumper, 6 – cover, 7 – tunnel of camera, 8 – camera, 9 – shift of vice, 10 – arm of spark striker, 11 – spark striker, 12 – specimen, 13 – vice, 14 – base plate, 15 – catch of spark striker, 16 – spring, 17 – shock absorber, 18 – isolating clamping ring

The generation of impact spark on the described test rig can be obtained by impact of sparker 11 at the smear of investigated alloy spread on the corroded specimen 12. Sparking ability of aluminum alloys depends, to a different extent in different ratio on the structure morphology of casting. An effect of applied purifying processes on the shape and temperature distribution in the plumes of impact sparks is shown in Fig. 12.

a)

b)

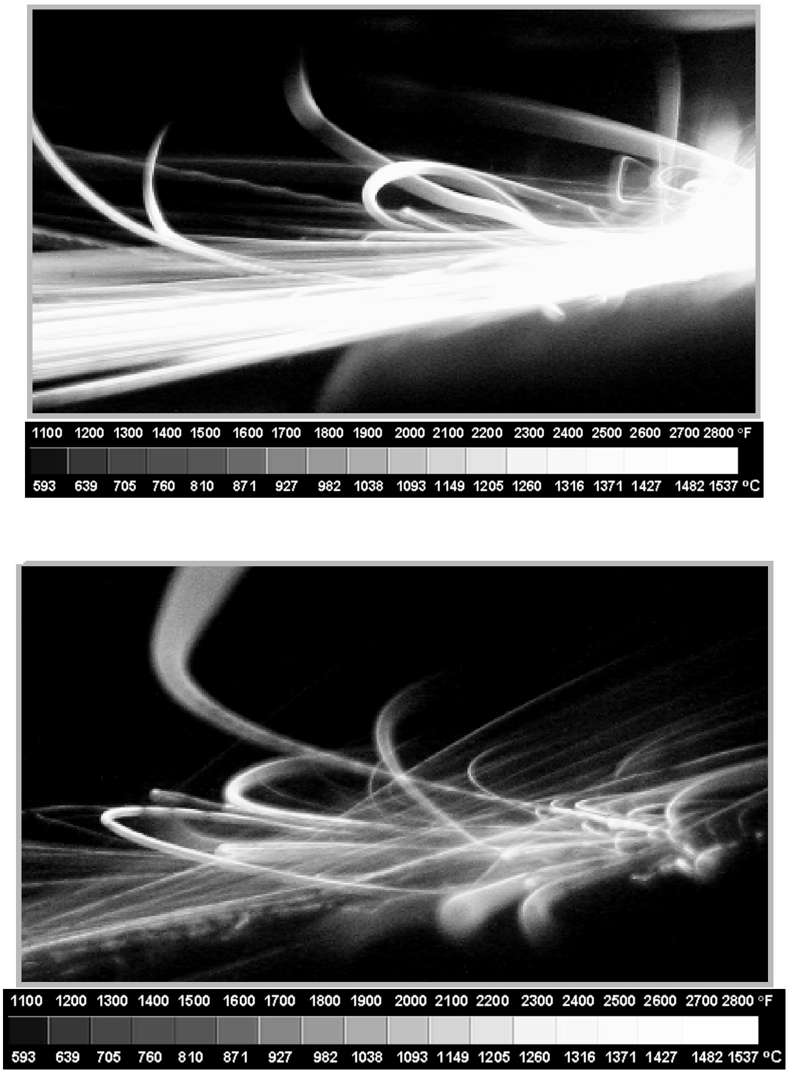


Fig. 12. Profiles of plumes and the temperature distributions in the impact sparks:
a) „hot” spark, b) „cold” spark

As a result of impact and friction of the striker at the investigated aluminum alloy smear it comes to the mechanical separation (tearing off) the hot particles from the solid body and their burning in the shape of the plume of impact spark. Digitally registered plumes of impact sparks from the smears of the non-purified and after purifying significantly differ from one another.

Temperature distributions in the plume of the impact spark generated by the non non-purified alloy show the values over 1500^{o}C (Fig. 12a). However, the temperature distribution in the plume of impact spark that was obtained from the impact spark of smear of the purified aluminum has greatly decreased (Fig. 12b) as compared to the plume of the spark of non-purified alloy.

3. Final remarks

The carried-out investigations permit to formulate the following remarks:

- it is possible to shape the convenient technological and mechanical properties of aluminum alloys by the application of the proper processes of the purifying these alloys;
- the purifying processes have generated the variation in the kinetic crystallization of aluminum alloys that were graphically registered by electrical – σ and thermal – t curves as well as by their first derivatives in the function of time;
- an effect of the changes generated in the processes of crystallization after the purifying of investigated alloys is the modified structure and consequently a significant increase in the strength R_m and very great increase in the plastic properties (A_5 and KCV) with regard to the alloys purified only;
- the purifying of modified aluminum by the process of filtration improves its structure by the decrease in the porosity, the removal of impurities and as a result the variation in the machining of manufactured castings;
- it is possible to increase the chosen technological properties, i.e. in the decrease in the sparking susceptibility by the double drop in the maximum temperature in the plume of impact spark.

It was stated, after the carried-out investigation of purified processes, that in the domestic manufacturing of aluminum alloys castings it is possible to obtain the castings of high mechanical and technological properties that are made of the charges materials of low quality (scrap) satisfying the buyer's requirements.

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