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INNOVATIVE ZINC ALLOY FOR PRODUCTION OF POSITIONERS OF CAR WINDOW ACCESSORIES

INNOWACYJNY STOP CYNKU DO PRODUKCJI POZYCJONERÓW OSPRZĘTU SZYB SAMOCHODOWYCH

***Summary**: The present paper is related to the problems of production of car window accessories from the modified foundry alloys of zinc. The material includes the results of the conducted industrial tests and developmental work. The range of the requirements for components and the properties of standardized materials were discussed. The innovative method for titanium alloying in the zinc ZnAl4Cu3 alloy was developed and described. The casts made from innovative materials, as produced in the demonstration line were subjected to a series of endurance (fatigue) tests.*

***Keywords**: positioners, car windows, zinc alloy, titanium, pressure casting*

***Streszczenie**: Artykuł dotyczy zagadnienia wytwarzania pozycjonerów osprzętu szyb samochodowych ze zmodyfikowanych stopów odlewniczych cynku. Materiał obejmuje wyniki przeprowadzonych badań przemysłowych oraz prac rozwojowych. Przedstawiono zakres wymagań stawianych komponentom oraz właściwości znormalizowanych materiałów. Opracowano oraz opisano nowatorską metodę stopowania tytanu w stopie cynku ZnAl4Cu3. Wytworzone w ramach linii demonstracyjnej odlewy z innowacyjnego materiału podano szeregowi badań oraz testom zmęczeniowym.*

***Słowa kluczowe**: pozycjonery, szyby samochodowe, stop cynku, tytan, odlewanie ciśnieniowe*

Introduction

Zinc alloys have many different applications in the car industry due to their properties which make that they are an attractive choice for many projects. They are often used in production of decorative elements inside and outside the vehicles where they are a perfect basis for coatings such as chrome plating. Such operation may include internal details such as door handles, knobs, dashboards elements and, also, external elements such as frames of windows or decorative elements on the car body. Due to the easiness of casting and good mechanical properties, zinc alloys may be employed in production of door locks, keys, regulation mechanisms and other elements connected with functioning of vehicle. The mentioned above alloys may be also applied in production of different electric and electronic elements in cars. They may include connection housing, fixing elements for conduits or shields of many types. Owing to their endurance, zinc alloys may be used in production of housing and protection of car elements such as sensors, transmitters or electronic modules. They may be also used in manufacture of different mechanical components which are not subjected to a great loading such as housing for engines of the car wipers, suspension parts or the elements connected with the exhaust system.

It should be noticed that the choice of zinc alloys in the car industry is dependent on the specified requirements for each component and the manufacturing costs. The alloys of zinc offer such profits as a perfect capacity of casting, good finish of surfaces, low melting temperature and favourable mechanical properties in the respective applications. However, due to a relatively low mechanical endurance as compared to certain other materials, it is mainly used in the sites where the dynamic or strength loading does not occur. Nevertheless, there are developed the methods for the increase of the casting strength of zinc alloys via thermal treatment or by alloying.

The increase of mechanical casting properties of zinc alloys

Owing to their favourable casting and utility properties, foundry zinc alloys are employed in a wide range. They demonstrate a low melting temperature any, consequently, a low casting temperature and good castability. They are especially suitable in casting under the pressure. The main alloy additives in zinc alloys include aluminium and copper. The small quantities of magnesium, manganese, iron, nickel and titanium are also introduced to zinc alloys. Aluminium prevents from solving of iron in the alloy, increases strength and improves castability of the alloy. Moreover, aluminium affects the anti-friction qualities. The lowest consumption is observed in alloys, containing ca. 5% Al and those ones with the content of aluminium in the limits of

14–30%Al. On the other hand, at the increased pressure of the order of 490 MN (50 kG), the lowest consumption occurs in the alloys with 14–26% Al content. Copper in the zinc alloys causes the increase of the inclination to spontaneous ageing; it affects, however, the increase of the strength, hardness and resistance to corrosion. In the alloys cast to metal moulds, the maximum tensile strength of Zn-Al-Cu alloys occurs at the 3.5–4.5% copper content. Hardness of alloys cast to sand as well as metal moulds is almost equal and is proportionally increased together with the increase of copper content, reaching value of ca. 90 HB at the addition of 5% Cu content. Copper added in the amount of 1–3 % decreases the inclination Zn-Al-Cu alloys to intercrystalline corrosion. The higher additives of copper increase the sensitivity of Zn-Al alloys to ageing and the related dimensional changes. Magnesium is added to Zn-Al alloys in the amount of 0.03–0.08% with the aim to reduce the unfavourable effect of contamination and, especially PB and Sn, and by this, to limit the intercrystalline corrosion. Magnesium has also the influence on inhibition of structural transformations, affects insignificantly the increase of the tensile strength and, simultaneously, decreases elongation. In the case of magnesium contents higher than 0.06%, the endurance qualities of ZnAl and ZnAlCy alloys are distinctly lower; the content of higher than 0.1% deteriorates castability, increases brittleness at hot and leads to cracking in the casts. Similarly as magnesium, titanium affects in a similar way and their respective additives may inhibit structural transformations and ageing processes. Iron in cast alloys of zinc should not exceed 0.03%. The higher iron content affects the deterioration of mechanical properties and machinability and the decrease of resistance to corrosion. Nickel in the quantity of 0.02–0.03%, as added to copper-free zinc alloy is favourable for improvement of mechanical properties and increase of resistance to corrosion in hot water and in vapour.

It is worth to be mentioned that the composition of the alloy additives and their quantities are adjusted according to the specified conditions and the intended properties of a final zinc alloy. It is important to carry out the studies and tests as to find the optimal combination of alloy additives which will meet the expected, specified performance and quality requirements.

Standardized zinc alloys

The obligatory standard in the discussed respect is standard PN-EN 1774: "Zinc and zinc alloys. Cast alloys. Ingots and liquid metal" and PN-EN 12844: 2001 – "Zinc and zinc alloys. Casts. Specifications". It is followed from the mentioned above documents that the most frequently applied alloy additive are aluminium and copper; however, there are also employed alloys, containing a small quantity of titanium (Tab. 1). The mentioned additives result in the change of mechanical properties but also, density or change in the range of melting temperature (Tab. 2).

Table 1. Chemical composition of casts from zinc alloys [1]

Signature of Zn alloy	Al	Cu	Mg	Ti	Zn
ZnAl4	3.7–4.3	0.1 max	0.025–0.06	–	Re
ZnAl4Cu1	3.7–4.3	0.7–1.2	0.025–0.06	–	Re
ZnAl4Cu3	3.7–4.3	2.7–3.3	0.025–0.06	–	Re
ZnAl8Cu1	8.0–8.8	0.8–1.3	0.015–0.03	–	Re
ZnAl11Cu1	10.5–11.5	0.5–1.2	0.015–0.03	–	Re
ZnAl27Cu2	25.0–28.0	2.0–2.5	0.010–0.02	–	Re
ZnCu1Ti	0.01–0.04	1.0–1.5	0.02 max	0.15–0.25	Re

Table 2. Properties of pressure casts from zinc alloy at temperature of 20°C (mean values, exclusively for the indicative purposes

Signature of Zn alloy	ZnAl4	ZnAl4Cu1	ZnAl4Cu3	ZnAl8Cu1	ZnAl11Cu1	ZnAl27Cu2	ZnCu1Ti
Tensile strength R_m. MPa	280	330	355	370	400	425	220
Total Elongation A_5, %	10	5	5	8	5	2.5	–
Brinell Hardness	97	114	130	95–110	95–115	105–125	–
Density, kg/cm³	6.7	6.7	6.8	6.3	6	5	7.2
Melting point range, °C	382–387	379–388	379–389	375–404	377–432	377–484	410–420

When comparing the data contained in Tab.1 and 2, it should be stated that ZnAl4Cu3 and ZnAl27Cu2 alloys demonstrated the highest hardness. It results from a high content of copper in the mentioned alloys (Tab. 2). However, due to a high content of aluminium in ZnAl27Cu2, the discussed alloy may be cast only in cold-chamber machines. Therefore, only the alloy with the chemical composition similar to that of ZnAl4Cu3 was considered in further tests aimed at the increase of strength properties. On the grounds of literature data [3–6], the addition of titanium at the level of 0.5% to ZnAl4Cu3 alloy was suggested.

The methodology of the studies

Casting and chemical composition of the test alloy

The studies on the possibility of alloying zinc with titanium were carried out in the industrial conditions, with the application of the industrial-scale demonstration line, consisting of two basic devices: induction furnace with overflow pump and hot-chamber high-pressure alloying machine Frech 125. Due to a similarity of construction of the structure of high-aluminium Zn alloys and the alloys based on Al (the presence of phase α in the both groups of alloys), the same mortars as for Al alloys were principally used for modification of alloys of zinc and aluminium. They include modifiers on the basis of Al which, however, require a considerable overheating of alloy what is unfavourable for its properties, and the application of immersing device in order to spread the mortar in metal bath. The mortars made on the basis of Zn e.g. ZnTi or ZnCuTi are deprived of the mentioned defects. The developed procedure of preparing the alloy is given below (Tab. 3). The new alloy has been called ZAMSINT.

Monitoring of chemical composition occurred during the whole process of alloy preparation. The cast was targeted at obtaining the chemical composition, amounting, respectively, to: 4% by weight Al, 3% by weight Cu and 0.2% by weight Ti. The analysis of the samples collected from the furnace of casting machine was carried out, directly after alloying as well as after separation of casting alloy at the period of ca. 16h (the alloy was hold in the preheating furnace until the next day) (Tab. 4).

The tests of the macrostructure of the samples, collected from the experimental products

The conducted experimental casts of zinc alloy ZnAl4Cu3 with different content of Ti were subjected to evaluation of macrostructure under microscope OLYMPUS SZX9. The exemplified macrostructures of ingot and die casting with the addition of Ti is given in Fig. 1 and 2. The die casting was performed from ZnAl4Cu3 alloy with the addition of Ti. We may observe a considerable effect of disintegrating impact of titanium.

Table 3. The procedure of preparing alloy of ZnAl4Cu3 with titanium

No.	Procedure of alloying:
1.	Load the induction oven with the first batch of ZnAl4Cu3 alloy (ingot)
2.	After melting the first batch of alloy, add the second part of ZnAl4Cu3 alloy
3.	Add AlCu mortar
4.	Wait for the complete melting at the full power of induction furnace (melting time ca. 1h:20min) temperature of the oven should amount to 440°C–450°C
5.	Add ZnTi2 mortar
6.	Check whether AlCu mortar has been dissolved (the mortar is lighter than ZnAl4Cu3 alloy and as being in a solid state, it flows out on the surface of the melted material)
7.	In the case of the incomplete dissolving of the mortar, wait for 15 minutes and again check the surface of the alloy in aspect of the presence of unsolved pieces of AlCu
8.	Transport the alloy to the oven of cast machine, using the pump, installed on the induction furnace

Table 4. Description of the samples, collected from the furnace, together with the measurement of their chemical composition

Description	Al	Cu	Ti	Mg	Fe	Zn
Chemical composition of the test alloy after alloying	4.45	3.15	0.558	0.035	0.0056	Re
Chemical composition of the test alloy after 16 h from alloying	4.12	2.98	0.35	0.035	0.0064	Re

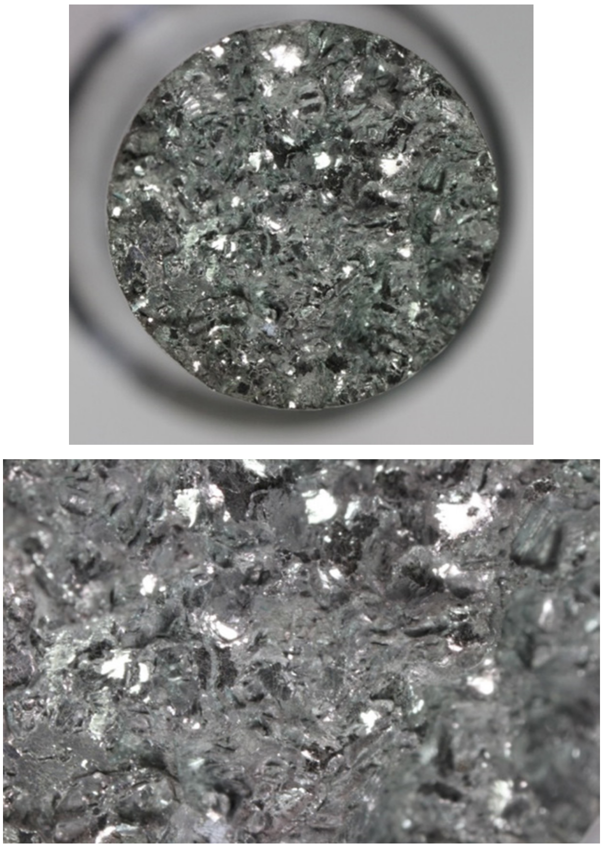


Fig. 1. Macrostructure of ingot

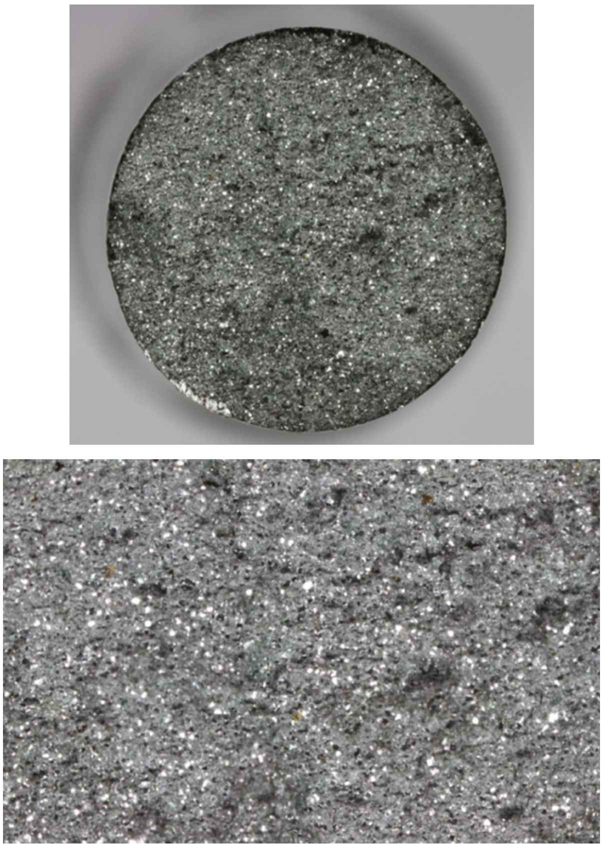


Fig. 2. Macrostructure of die casting from ZnAl4Cu3 alloy, modified with Ti

Testing of mechanical properties

The details, cast in the suggested technology, were subjected to a series of mechanical tests. At first, the tests with the samples cast in semi-industrial conditions to steel ingot mould were carried out. The alloy was prepared in resistance furnace, with mechanical agitation. In order to dissolve AlCu mortar, the overheating of the alloy up to 550°C was employed. Final content of titanium in the alloy was equal to 0.5% by weight. The endurance of the die-cast alloy, tested in the cylindrical samples performed according to PN was 265 MPa and the plasticity limit – 250 MPa. High-pressure casting is, however, characterized by significantly different conditions of the alloy's crystallization what gives, in effect, completely different mechanical parameters of the finished detail. Moreover, the casts made in the discussed technology are usually thin-walled what is favourable for better removal of heat, quicker crystallization and, in effect, disintegration of the alloy's microstructure. We should, therefore, expect considerably better strength parameters. The resulting cast has a complex shape, possessing the walls with a different thickness in its cross-section. As it is followed from the porosity tests, it is mainly perceived in the central part of material. The additional problem during the tests concerned a small dimension of the discussed detail, giving a small freedom to preparing the sample to the mechanical tests. Within the frames of the existing possibilities, the method for cutting out the samples for tensile strength tests was suggested (Fig. 3). The mentioned tests were carried out at the ambient temperature (Fig. 4). All tests were conducted with the test ZnAl4Cu3 alloy with titanium content amounting to 0.2% by weight. The discussed tests were implemented with the samples, collected from the stabilised part of the casting process, i.e. after thirtieth injection.

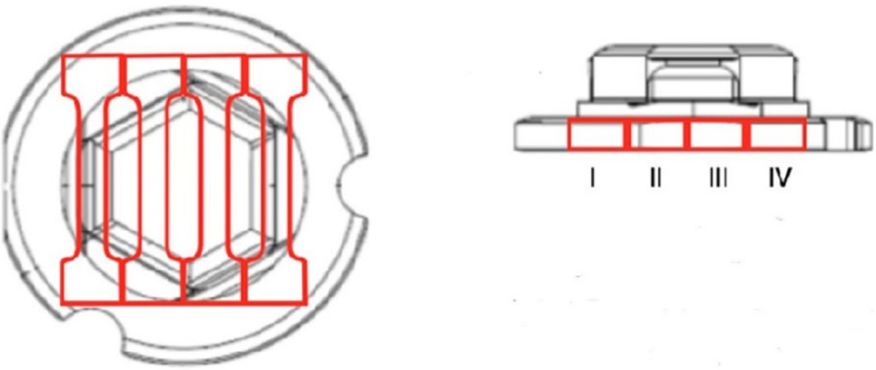


Fig. 3. A scheme of cutting out the samples for mechanical tests

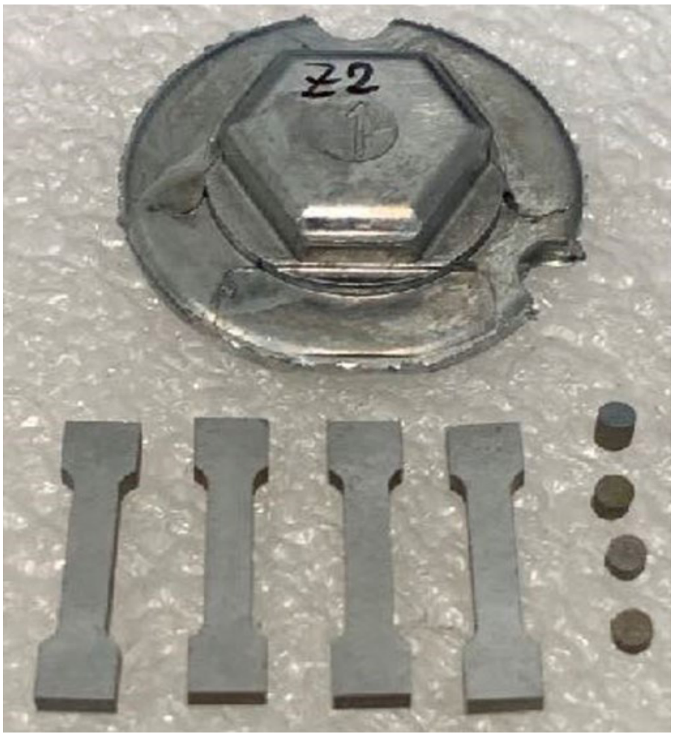


Fig. 4. Photos of the samples cut out for mechanical tests

The results of the tensile strength tests are given in Fig. 5, illustrating the strain-stress curves for the samples cut out from the casts. A strong correlation of the results is visible and the mean values presented in the table indicate that the tested material had a better strength than the material cast by gravitation. The differences in the elongation values may indicate the presence of micro-porosity in the middle part of the cast which was also present in the strength-tested samples. The mean hardness of material in this state was equal to 110HB.

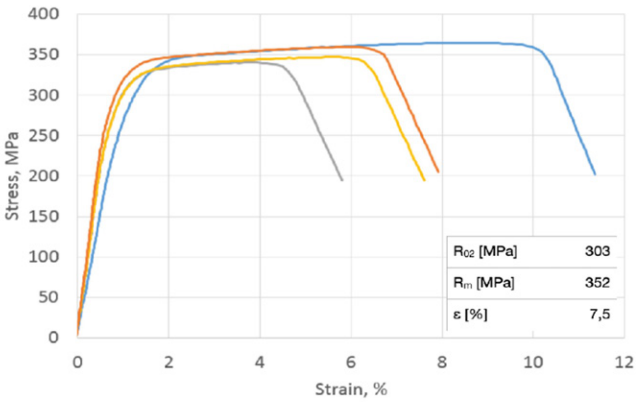
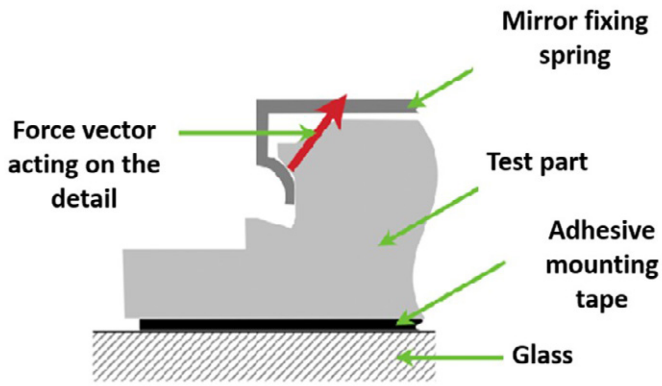


Fig. 5. Summary of the tensile strength tests for the samples from the research casts

Loads affecting the assembling detail of mirror

The measured mechanical parameters are the basis for confirmation of the alloy's suitability when applied to the loaded constructional elements. Apart from the material parameters, the correct analysis must consider the distribution of forces in the functioning detail. Due to its complex shape and complex scheme of strains for determination of maximum strains, the finite element method in respect of elastic strains, has been employed. To this end, the simulation package, as contained in SolidWorks software, has been utilized. For the needs of simulation, the simplified model; the forces affecting the detail were applied in parallel to the surface of "wings", transferring the load. The mentioned model together with the results of stimulation in a form of distribution of the equivalent (reduced) stress is given in Fig. 6.



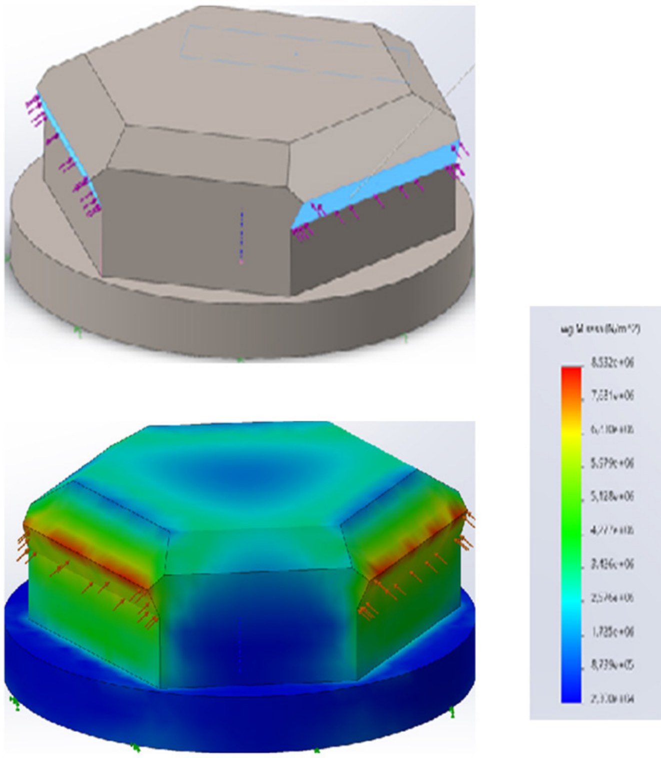


Fig. 6. Images of simulation of load, conducted in a model of detail, at the loading of the element with 30 kg weight

For the purpose of simulation, the force of 100N was applied; it was evenly distributed on the working surface of each of the 'wings' what corresponds to theoretical load of the detail with the element with 30 kg weight. The maximum calculated reduced stress amounted to 8.5 MPA, the analysis should be however extended to the situation of the mot unfavourable case of loading, i.e. when only one "wing" transfers the whole force (e.g. during bending of the mirror, fixed in the handle). In such situation, the application of the force corresponding to 100 kg load will increase the maximum stress in detail to value of 85 MPa. The calculated stress is still more than twice higher than the recorded one in tensile strength test at temperature of 100°C. It should be stressed that the above discussed calculations refer to extremely unfavourable loading conditions (in fact, the mirror fixing spring will give up at twice lower loads). The scheme of stress acting in detail is also more similar to compression or shear, so the comparison with the tensile strength test is an underestimation of the possibility of transferring the load by the mounting element. Summing up, the element cast from ZnAl4Cu3 alloy, being alloyed with Ti meets the safety requirements in aspect of the transferred static loads. The mentioned calculations have been confirmed in the presented below tests of loading of details with a constant force at the increased temperatures. Summing up, the static mechanical parameters of the examined components are considerably better than the previously presented mechanical parameters, obtained in the tests in ZnAl4Cu3 alloy with Ti, cast by gravitation, and they are fully sufficient for assurance of safe use of mounting element.

We should, however, mention that zinc alloys, possessing a relative low melting temperature as compared to other metallic constructional materials, may demonstrate unfavourable phenomena during loading in respect of alloy creep and high-cycle fatigue. Due to this reason, there were prepared and conducted the tests, considering the mentioned above phenomena in the context of fatigue work.

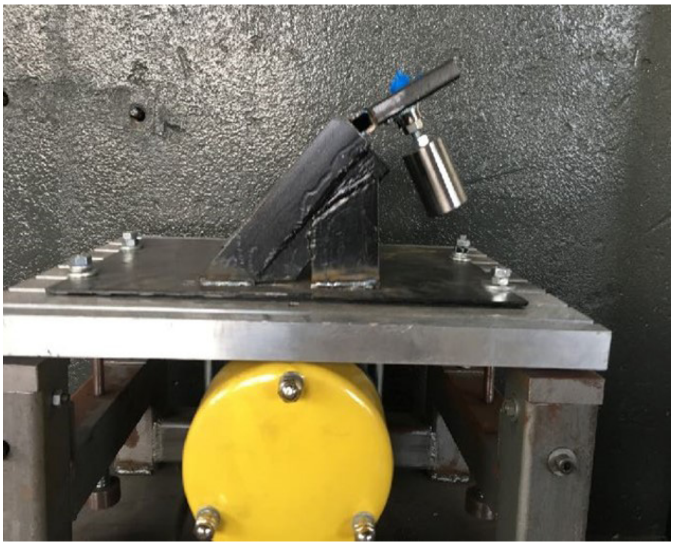


Fig. 7. Photo of a stand for fatigue tests with the assumed dedicated handle (grip)

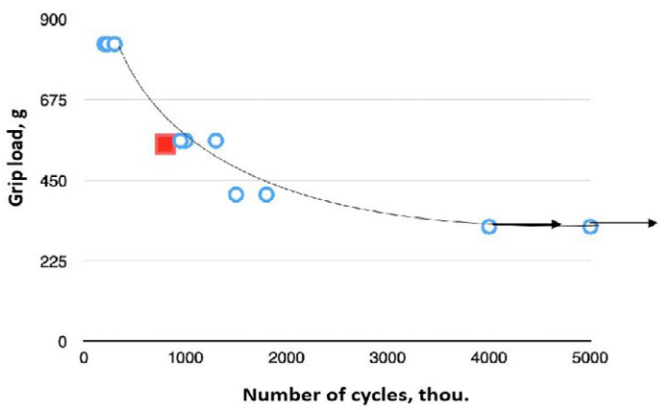


Fig. 8. Technological fatigue curve, representing the strength of detail, made from the tested ZnAl4Cu3 alloy with Ti, according to the number of cycles and load

Fatigue tests

The industrial fatigue tests were carried out on the produced details made from ZnAl4Cu3 alloy, alloyed with Ti and cast by high pressure technology. The mounting part decides on the endurance (strength) of the total element, transferring the load by the dedicated steel spring on the construction of the mirror. The element transferring the load is only a small part of the total detail what precludes making a sample for standardized fatigue tests. Due to this reason, we decided to conduct the industrial tests under the conditions, reflecting the work of the total assembly: glass-mounting handle-mirror. To this end, there was designed and performed a dedicated stand for the tests (Fig. 7). Its basis is created by vibration table, equipped with vibration motor, with an adjusted position of eccentric mass and frequency of work. The tested detail was fixed to glass background, equipped with the mounting system used in motor industry, utilizing a dedicated double-side tape by 3M company. The prepared set was mounted in the frame, screwed to T-table with construction enabling its positioning at the angle of 30 angular degrees what reflects the work under the operating conditions of car. All fatigue tests were carried out at a room temperature with frequency of 50 Hz and the recorded amplitude of vibrations (at the mirror), amounting to 1.5 mm. The fatigue destruction in the test with the application of original mirror, having a weight of ca. 550 g occurred after 800 thousand cycles and the cracking had place in the spring assembling part of the mirror and the tested detail remained intact. The discussed result is the evidence that the steel spring of the mirror is the most strained part of the total mounting set.

In further tests, the mirror was replaced with dedicated handles made from tool steel. The load was shifted in relation to mounting part so as to obtain the centre of gravity of the system analogical to that of real mirror. The tests were carried out for different loads and their result in a graphical form, analogical to Wohler curve is given in Fig. 8. If we adopt the fatigue strength of original mirror as equal to 800 thousand cycles with the assumed boundary conditions of vibrations, the cast details from ZnAlCu3 alloy, alloyed with Ti are found in the range, ensuring the safety of use.

Summing up

Within the frames of the implemented research-developmental work, the standardised ZnAl4Cu3 alloy was modified by addition of a new alloy component: titanium. It received the name: ZAMSINT. The developed innovative method of alloying in the induction furnace determines the maximum content of titanium addition at the level of 0.5%. There were also conducted the cast tests by gravitation method and with the application of high-pressure hot-chamber machine. The obtained components were controlled with the employment of the macroscopic tests, tensile strength tests, computer simulation of the strain and dedicated fatigue tests. All above mentioned operations have confirmed the correct properties of the alloy in relation to the basic material. The fatigue tests, as performed at the stand, simulating the real conditions of work have revealed the possibility of safe utilization of the set, consisting of the component made from ZAMSINT alloy at the level of 800 thousand cycles, satisfying the safety requirements of the discussed elements.

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