APPLICATION OF ALUMINUM ALLOYS FOR COMBUSTION ENGINE BEARINGS

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Abstract

In most cases the choice of proper alloy for combustion engine crank mechanism bearings means a compromise between various requirements. In order to increase the fatigue strength and to enhance the wear resistance the research on new materials, including the aluminium alloys, is being carried out.

This paper deals with properties of aluminium bearing materials, requirements relative to their operation as well as tendencies of their future development as the bearing alloys for heavy duty diesels.

Interdependences affecting bearing properties, comparison of tested bearing materials fatigue strength, controlled distribution of Si particle size in analysed bearing alloys, comparison of fatigue strength of bearing materials subjected to tests, the wear of analysed bearing alloys after engine tests are illustrated in the paper. The paper concentrates on the problems of properties of aluminium based bearing alloys, tendencies in development of aluminium alloys for highly loaded crank bearings of IC engines. Bearing of Al-Sn-Si alloy operates satisfactorily on an engine and have high fatigue strength (particularly on diesels) and posses high wear resistance, especially for a case of frequently started and stopped engine (gasoline engine) which causes difficulties in formation of continuous oil film at low crankshaft speeds.

Keywords: *combustion engine, slide bearing, aluminium alloys, properties, new Al-Sn-Si alloys*

1. Introduction

Selection of a suitable alloy for bearing shell material is always a kind of compromise between different requirements which bearing construction should face. Most often the bearing material should reveal high mechanical strength (fatigue on, in particular) corresponding to the load and operational temperature, advantageous slide properties (due to the shortage of fluid lubrication at low rotational speed during engine start and stop), compatibility, embedability of hard particles carried with lubricant, high resistance to abrasive and corrosive wear (including chemical corrosion due to the acid products of lubricant decomposition), good conformability to journal minor shape errors and deflections. Alas, practice does not know material which satisfies all presented requirements. These requirements are partly contradictory, e.g. a high resistance to the abrasive wear at high load needs high yield point while this point should not be too high because of proper conformability to the journal deformations. As one can notice, requirements relative to bearing material properties are to the far extent contradictory. This makes that there is a constant need for new bearing materials that could combine these requirements with expectations of manufacturers resulting from mechanics, tribology and economy. Besides of material these efforts should take into consideration technology, i.e. machining or foundry. Correlations between material engineering and manufacturing techniques that affect bearing properties have been presented in Fig. 1.

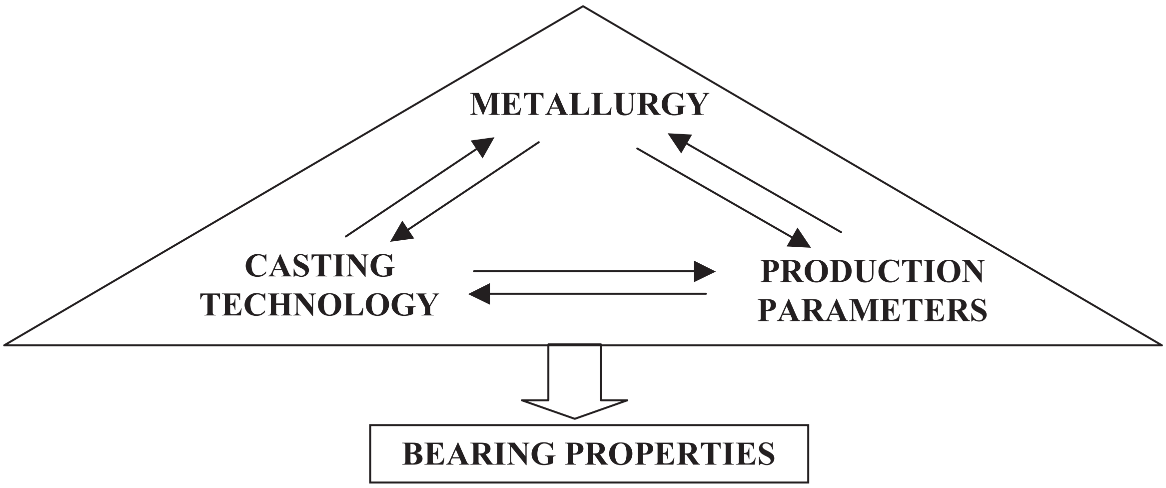

Fig. 1. Interdependences affecting bearing properties [3]

The set of materials that can be applied to the engine crank mechanism bearings includes: white metals (high- and low-tin alloys as well as cadmium alloys), copper based alloys (bronzes), aluminium alloys or occasionally met zinc or silver alloys. At present, EU regulations relative to the 2000/53/EC Directive concerning the vehicle withdrawal from operation affect to the far extent the application of certain alloys for bearing materials [1]. This Directive contains future standards for lead or cadmium (as alloy component) content in parts of vehicles. This made bearing material manufacturers to turn their interest toward those bearing alloys that do not contain those two elements. A stress has been put on aluminium alloys for two and three layer bearings.

2. Properties of aluminium based bearing alloys

Various elements can be used for crank mechanism slide bearings of aluminum matrix, namely: tin, silicon, zinc and lead [5].

Aluminium-tin bearings are usually made by roll bonding the alloy to steel strip. Higher contents of tin (up to 25%) gives higher scuff resistance but lower elastic limit, ductility and rupture strength as soon as contents of tin exceeds 10% (a tendency of tin continuous phase formation along aluminium particle edge is being observed). A compromise solution seems to be the alloys of AlSn6 type, applied to trilayer*, thin bearing shells.

Aluminium-tin alloys of AlSn type (e.g. AlSn20CuNi) rolled over thin steel strip and tempered are widely used for IC engine bearings. A fragile structure of tin continuous phase surrounding aluminium particles is damaged in the process of plastic working (rolling) and tempering (recrystallization annealing). A broken space matrix of squeezed tin is formed around aluminum particles not on their surface (“mesh alloy”).

The AlSn20 alloy can satisfactorily collaborate with unhardened journals, but the wear of journals is higher than those collaborating with white metals. It is why certain bearing manufacturers increase the tin contents up to 40% which gives a higher strength and higher fatigue replacement for white metals. The hardness of Al alloys depends on their composition and heat treatment (alternatively on plastic working) and is situated in a wide range 25 – 120 HB.

Also aluminium alloys of the Al-Sn type (e.g. AlSi12CuNi, AlSi11Cu and AlSi4CuMg) purposed for highly loaded bearings, those experiencing the oscillating work in particular (e.g. pin bearing) belong to the group of bearing alloys with aluminium matrix. Their characteristic features are: elevated fatigue strength, superior corrosion resistance and high wear resistance. Their hardness is 110 and 95 HV at 50 and 150^{o}C, respectively.

* Electroplated tri-component overlay of PbSnCu alloy constitutes the third layer.

Cast or rolled aluminium alloys of Al contents up to 95% were used for engine bearing in the USA. A variation of these alloys is the one containing 5% Pb dispersion in aluminium layer of 0.45 mm thick. For properly performed casting about 8% Pb appears on sliding surface whereas just 3% Pb near the steel basis, which ensures high strength of the connection[*].

Most often the aluminium alloys are spread over steel backing (bi- or trimetal bearings) but also can come along as monoliths. The most important advantages of aluminium alloys are: high heat conductivity, low specific mass, superior anticorrosive properties, good machineability. Alas, they have also disadvantages like: relatively high coefficient of thermal elongation (can lead to the change in bearing clearance) and poor slide properties at oil starvation.

3. Tendencies in development of aluminium alloys for highly loaded crank bearings of IC engines

Constant efforts on development of bearing materials are being carried out to meet the requirements of automotive industry. These efforts are directed on proper matching of the shell material to bearing run conditions, high resistance to corrosion, low contents of lead (because of its toxic properties) and low cost. Beside perfect fit the bearing material should secure appropriate fatigue strength because of oil film pressure and adequate resistance to wear and seizure that could occur during start and stop when there is a high danger of oil film rupture. The bearing materials that could meet all these requirements are aluminium alloys. They are applied mainly for automotive engine bearings as thin wall double layer shells (often with an intermediate layer).

At the moment tests are being carried out on improvement of Al-Sn type aluminium alloys with addition of silicon. Tin phase provides plasticity of the alloy while hard silicon particles give suitable fatigue strength and resistance to seizure and wear. The intermediate layer – softer than basic bearing material – improves conformability and can serve as a cushion if an edge load is applied to the bearing. The intermediate layer most often made of pure aluminium (or its alloy) is located between the bearing alloy layer and the steel backing in order to stabilize the bonding of those layers.

The research on Al-Sn-Si type alloys is directed towards material of high fatigue strength and high resistance to wear.

This research should give not only the best bearing material but also suitable intermediate layer. Tests carried out by Kagohara et al [4] concerned the alloy of elevated fatigue strength and included bearing alloys and intermediate layer of chemical contents and mechanical properties presented in Table 1. The bearings tested were the crank bearings made of Al-Sn-Si type bearing alloy typical for automotive engines (bearing No 1) and of newly developed bearing material appropriately machined (bearing No 2).

Tab. 1. Chemical contents and mechanical properties of bearing alloy and intermediate layer [4]

Bearing No	Bearing alloy				Intermediate layer	Mechanical properties			
	Chemical contents [% mass]				Chemical contents [% mass]	Alloy hardness [HV]	Intermediate layer hardness [HV]	Tensile strength [MPa]	Elongation [%]
	Al	Sn	Si	Cu					
1	rem	12	2,5	0,7	> 99%Al	42	30	137	30
2	rem	10	2,5	1,5	98,7% Al +1,3% Mn	57	50	183	22
					92,5% Al. + 7,5% Si				

[*] During Al casting on steel backing fragile Al-Fe compounds emerge which decrease alloy to back adhesion.

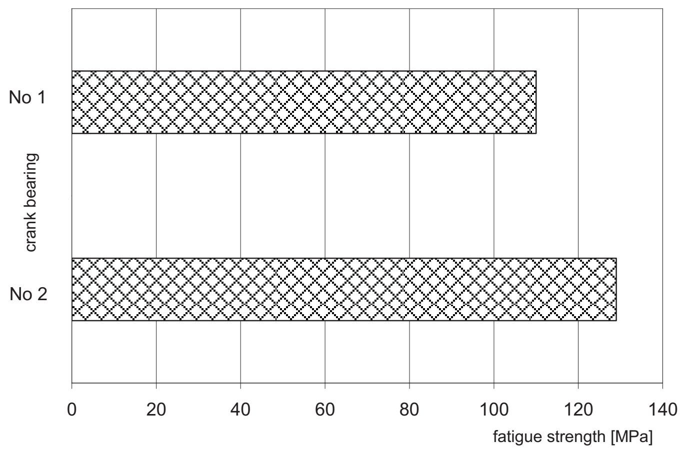

Fig. 2. Comparison of tested bearing materials fatigue strength [4]

Further tests were directed toward the size of Si particles in bearing material in order to obtain a bearing alloy of higher wear resistance without any decrease in fatigue strength. Hard particles of silicon distributed in soft Al-Sn matrix give smaller scratches on cast iron journal surface, decrease a bearing alloy wear and facilitate the covering of journal with additional materials. The carried out test [4] are to answer how to improve the anti-wear properties without any fall in bearing alloy fatigue strength. One of the possible ways is to control distribution of certain Si particle size in whole volume of alloy. The test were carried out for 4 bearing alloys (see Table 2) where the alloy No 1 was the conventional one, whereas the remaining 3 had 10% contents of tin (mass) and differed one from another in the size of Si particles. The size of Si particle was reduced to the diameter observed with microscope (μm) and related to the whole surface observed (%) (see Fig. 3).

Tab. 2. Chemical contents of bearing alloy [3]

Denomination of bearing alloy	Chemical contents [%]				Remarks
	Al	Sn	Si	Cu	
No. 1	rem.	12	2.5	0.7	Conventional alloy
No. 2	rem.	10	3.0	1.0	Particle distribution as in conventional alloy
No. 3	rem.	10	3.0	1.0	Controlled and arranged Si particle distribution,
No. 4	rem.	10	3.0	1.0	Particles bigger than in conventional alloy

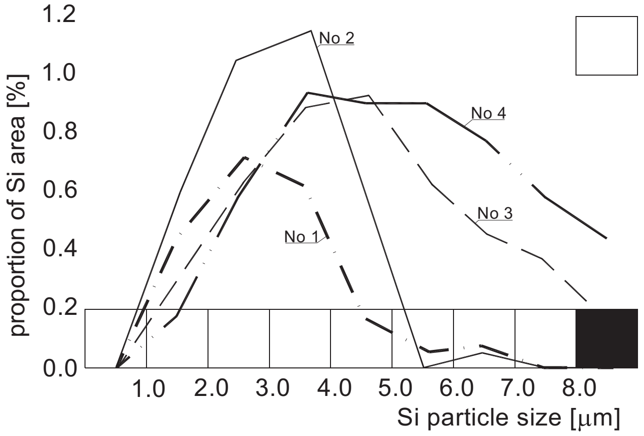

Fig. 3. Controlled distribution of Si particle size in analysed bearing alloys [3]

Bearings made of materials presented in Table 2 were subjected to wear and fatigue tests. Results of the wear test are as follows [3]:

– the wear of bearings No 1 and 2 is the same, increase in Si contents does not reduce wear,
– bearing No. 3 shows triple increase in wear resistance comparing to the bearing No. 1.

Results of the fatigue test are presented in Fig. 4. The lowest fatigue strength among all tested bearings has been noted for the bearing No 4 with biggest Si particles. In the case of bearing No 3 with controlled distribution of Si particles no traces of fatigue wear has been observed for the load conditions similar to that for bearing No 1. One may conclude that bigger Si particles could reveal the notch effect and accelerate the fatigue crack occurrence whereas the smaller particles could prevent this effect. Moreover, the presented results suggest that a controlled distribution of particle size, i.e. coexistence of small and big Si particles is the way to reduce wear without any decrease in fatigue strength.

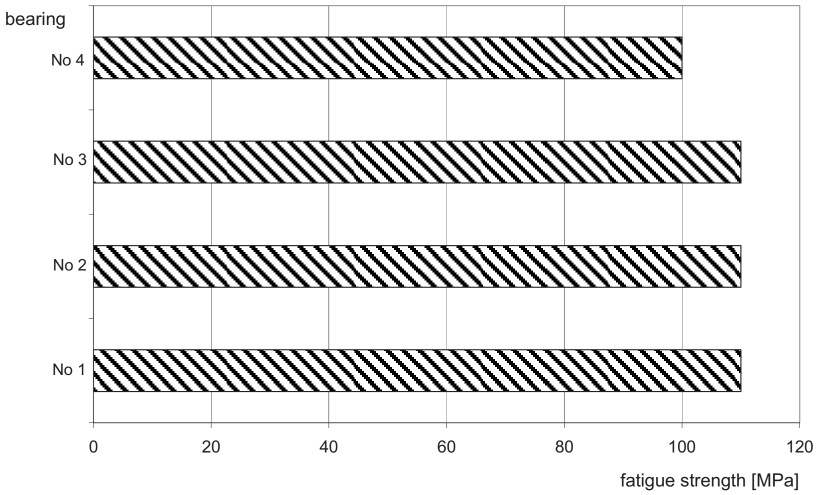

Fig. 4. Comparison of fatigue strength of bearing materials subjected to tests [3]

In order to finally evaluate the new bearing material tests have been carried out on a test bed equipped with a gasoline engine. The main bearings were made of bearing material No 1 and No 3. A durability test consisted of 10,000 "start and stop" cycles has been carried out. Fig. 5 presents the results of wear tests carried out on test stand. There are no traces of wear like scratches or fatigue on the surface of bearing shell. The bearing alloy used for the bearing No. 3 has almost seven fold better anti-wear properties than the traditional one (bearing No 1).

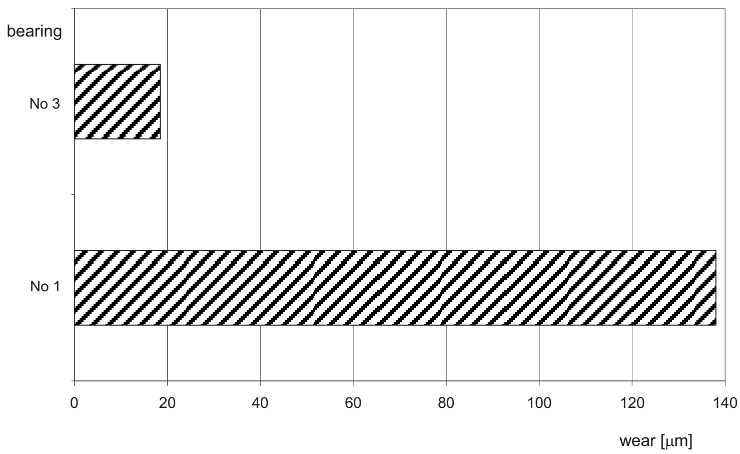

Fig. 5. The wear of analysed bearing alloys after engine tests [3]

4. Summary

When the bearing of Al-Sn-Si alloy is to operate satisfactorily on an engine it should have high fatigue strength (particularly on diesels) and posses high wear resistance, especially for a case of frequently started and stopped engine (gasoline engine) which causes difficulties in formation of continuous oil film at low crankshaft speeds. A way to fulfil this requirement is to introduce a layer of Al-Si alloy between the intermediate layer of Al-Mn and steel backing, which lead to a minimization of fragile phase that could occur at the boundary region during the heat treatment. Due to that higher temperature can be applied and achieve higher fatigue strength of bearing alloy. The controlled distribution of silicon particle size (concurrent presence of smaller and bigger Si particles) seems to be a way to improve wear resistance. The presence of big Si particles increases the wear resistance without any loss of fatigue strength.

In authors' opinion the efforts on the utilization of aluminium-tin-silicon alloys for sidle bearings of highly loaded combustion engines should be continued as these alloys are to replace copper-lead alloys with lead containing overlay. Further tests should concern optimum contents of the overlay and intermediate layer, and methods of heat treatment as well.

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