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Combustion Engine Cylinder Liners Made of Al-Si Alloys

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Abstract

The paper deals with problems related to application of aluminum-silicon alloys for combustion engine cylinder liners.

Keywords: Combustion engine cylinder liners, Al-Si alloys

1. Introduction

The reason for which a fast growth of applications involving aluminum-silicon alloys can be observed in the automotive industry over recent years include the high value of ratio of the tensile strength to the mass density, good corrosion resistance, good technological properties, and low manufacturing and processing costs characterizing these materials.

Nowadays, in view of more restrictive requirements concerning emissions of exhaust fumes, car engine manufacturers use prefer castings of light metal alloys in order to reduce engine mass which in turn allows to reduce fuel consumption. In view of the above, aluminum-silicon alloys have been relatively early used to fabricate engine cylinder heads, cylinder blocks, oil sumps, and brackets. For a long period of time, a serious problem related to manufacturing of cylinder liners of aluminum-silicon alloys consisted in making them resistant to abrasive wear and seizing.

In recent years, a number of scientific centers have continued their work on the possibility to use that alloy for fabrication of combustion engine cylinder liners cylinder in view of its good sliding properties and high resistance to abrasive wear.

Rare results of studies presented in the latest international literature [1–3] indicate that scientific and research studies on the

wear properties of engine cylinder liners made of aluminum-silicon alloys are currently continued (e.g. at GM Powertrain, General Motors Co, in Pontiac and Wixom, as well as at GM R&D Center, and General Motors Co in Warren).

2. The state of art

Aluminum-silicon alloys used as a material for combustion engine cylinder liners are attractive in view of some of their specific properties, namely:

- good thermal conductivity;
- value of the coefficient of thermal expansion close to this characterizing the piston;
- good behavior in technological processes (casting and machining);
- good immediate and fatigue strength;
- corrosion resistance in the atmosphere of fuel combustion products;
- possibility to shape cylinder bearing surface geometrical properties facilitating retention of lubricant;
- sufficient resistance to abrasive wear.

Another important merit of Al-Si alloys is their relatively low specific weight which allows to reduce the overall mass of the engine. Thermal conductivity of these alloys is about three times higher than this of cast iron which offers the possibility to reduce temperature of the cylinder liner working surface at the same engine power output. An engine block made of such alloy gives up the heat faster and more evenly, therefore less coolant is needed in the cooling system. Thanks to similar value of the coefficient of linear thermal expansion characterizing both the cylinder liner and the piston, it is possible to maintain high stability of the piston play, regardless on the engine operating conditions. In view of low casting temperature, thermal load on the mould is relatively low in case of aluminum-silicon alloys. For this reason, it is possible to fabricate castings with a higher dimensional accuracy and better surface quality which in turn makes the machining costs lower. Aluminum alloy castings can be manufactured in permanent metal moulds which translates directly into lower manufacturing costs. Aluminum-silicon alloys are considered well-machinable materials, even if their machining properties deteriorate with increasing silicon content.

By performing such operations as modification of liquid metal and selection of appropriate cooling rates, it is possible to increase significantly both immediate and fatigue strength of Al-Si alloys and improve their resistance to abrasive wear. On the other hand, thermal treatment aimed at improvement of resistance to abrasive wear is not always appropriate, especially in case of castings manufactured with the use of conventional pressure casting method which can result in dimensional instability caused by gas porosity. Aluminum-silicon alloys demonstrate satisfactory corrosion resistance in the atmosphere of fuel combustion products.

Studies on application of aluminum-silicon alloys are carried out mainly by industrial laboratories and therefore results of such studies are rarely published in commonly available technical literature, hence the lack of sufficiently in-depth knowledge concerning the most favorable microstructure of castings for cylinder liners and geometrical parameters of the cylinder bearing surface profile securing sufficient retention of lubricant.

Maintaining adequate thickness of the lubricant layer is of critical importance at the stage of engine starting. Available knowledge on this subject is limited to cylinder liners made of cast iron. It is a well-known fact [4] that if the metallic contact between the piston ring and the liner does not occur for 99.9% of the engine running time, then the wear is insignificant. If, however, the metallic contact exists for 1% of the engine running cycle, then the wear becomes high. For contact times longer than that, piston rings can break resulting in piston seizure.

To improve lubrication of the cylinder bearing surface, an operation known as honing is performed which consists in providing the surface with grooves in which engine oil is retained. According to [5], in case of providing a cylinder with grooves of constant depth and width, piston rings squeeze the oil out along the grooves (Fig. 1). This can result in excessive reduction of

lubricating layer on the cylinder load bearing surface. As a result of local contact occurring between an irregularity on the liner surface and the piston ring surface, abrasive wear will increase which can result in piston seizing. If appropriate hollows are made in the cylinder liner surface, such depressions, once filled with engine oil, constitute micro-areas of hydrodynamic lubrication. As a result, both friction and the associated wear decrease (Fig. 1). This is the reason for which many research projects are undertaken on such shaping of cylinder liner surface. In case of cast iron liners, laser micro-machining method can be used for this purpose [6], while etching is preferred in case of Al-Si alloys.

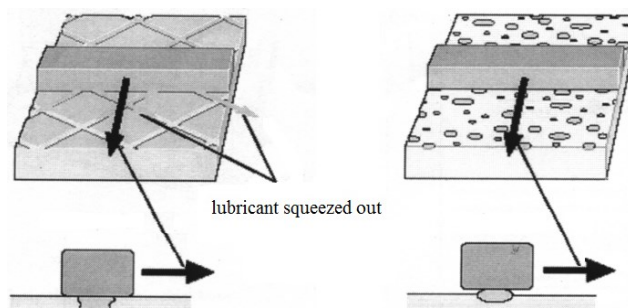


Fig. 1. Schematic diagram showing interaction between grooves and cavities filled with a lubricant on the piston ring/cylinder liner surface contact

The first attempts to fabricate cylinder liners from aluminum-silicon alloys were carried out towards the end of the 1970s. As it follows from technical literature of the subject, the monoblock of Vega 2300 engine, monoblocks for such cars as Porsche 911, Porsche 928, as well as those for certain models of Jaguar, BMW, Mercedes, and Audi cars were or currently are manufactured from AlSi17Cu4Mg alloy according to a technological process patented under the trade name ALUSIL[®] [7, 8]. Scarlet [9] reports that cylinder liners in the BMW Boxter engine, in a block made of a magnesium alloy, were made of an aluminum-silicon alloy containing 20% silicon and reinforced with Al₂O₃ fibers. The technological process used for fabrication of such liners has been patented under the trade name LOKASIL 1[®]. From other published studies it follows that cylinder liners are manufactured also of Al-Si alloy containing 27% silicon reinforced with Al₂O₃ fibers. The technological process for fabrication of such cylinder liners has been patented under the trade mark LOKASIL 2[®] [10].

Available technical literature of the subject reveals information about chemistry of aluminum-silicon alloys used specifically for cylinder liners (Table 1) together with data concerning their microstructure and service properties.

Table 1.

Chemistry of aluminum-silicon alloys used for engine cylinder liners (in % mas.)

Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Cr	Al	Source
11.8–12.7	0.15	1.15–1.45	0.09	1.2–1.5	0.85–1.15	0.04	0.09	–	balance	[1]
16–18	0.5	4–5	0.1	0.45–0.65	–	0.1	–	–	balance	[2]
17	5.0	3.5	–	1,1	–	–	–	–	balance	[3]
11.5	0.9	1.15	0.1	1.1	2.5	0.01	0.2	–	balance	[4]
17–19	0.7	0.8–1.5	0.2	0.8–1.3	1.3	0.2	0.2	–	balance	[11]
16–18	0.5	4–5	0.1	0.4–0.6	–	0.1	–	–	balance	[11]
22	0.4	1.6	0.3	1.6	0.7	–	–	–	balance	[11]

In the ALUSIL[®] process, AlSi17Cu4Mg alloy is used, whereas LOKASIL[®] technology utilizes an aluminum-silicon alloy containing 20% Si (LOKASIL 1[®]) or 27% Si (LOKASIL 2[®]) [12].

It is known from the literature of the subject [13] that low content of Mn and Cr favors development of needle-shaped phases. Such iron-containing needle-shaped intermetallic phase itself in reduction of thermal conductivity. However, an addition of Mn (Fe/Mn ratio = 0.5) changes its habit from needle-shaped to this resembling Chinese writing, mitigating the negative impact on the heat conductivity. Higher chromium contents are favorable to occurrence of phase precipitations in the form of polygons. An addition of Fe and Ni allows to reduce Cu content without affecting the tensile strength. Fe increases hardness, and moreover, alloys with low iron content are more expensive. Additions of Mg and Cu are practiced in order to increase tensile strength and creep resistance. An addition of about 0.5% Ni also has a positive effect on creep resistance. Moreover, it must be borne in mind that currently, monoblocks are cast with the use of the pressure casting method. Typical alloys such as 226, 230, or 231 contain usually about 1% Fe. US founders use alloys containing even up to 2% Fe, in view of the need to reduce susceptibility of castings to sticking to the mould.

On the other hand, there is very little information concerning microstructure of the used materials as well as geometrical parameters characterizing profile of bearing surface samples. It seems that using alloys with hypoeutectic or eutectic composition as a material for cylinder liners can turn out to be purposeful in case of special techniques of coating bearing surface with a layer of material resistant to abrasive wear, e.g. chromium or iron, or in case of applying cast-in sleeves. In view of specific conditions prevailing in the course of filling a pressure mould with liquid metal in conventional pressure machines and high solidification rates, the most compact structure of the casting is obtained in its regions close to its surface. In areas situated deeper, some porosity may develop which reduces resistance to abrasive wear. Higher compactness of the casting material can be obtained when low-pressure casting methods or pressure methods with negative pressure in the mould cavity are used, such as e.g. the VACURAL[®] method.

Surfaces of castings which are required to show elevated resistance to abrasive wear must be provided with cast-in sleeves made of alloys characterized with high resistance to abrasive wear. In case of engine blocks made of aluminum-silicon alloy, it seems to be purposeful to perform cast-in components of hypereutectic silumin, with microstructure and surface geometrical structure guaranteeing satisfactory resistance to abrasive wear and seizing. The required geometrical structure of

the cylinder bearing surface must be in this case shaped as a cast-in element by means of etching methods. An example of casting provided with a cast-in component is shown in Fig. 2.



Fig. 2. An example casting with a cast-in component

3. Conclusions

It follows from the state of art in the area of selecting chemistries for aluminum-silicon alloys used for combustion engine cylinder liners that it is reasonably practicable to provide them with cast-in elements of alloys containing even as much as about 30% silicon, as in the patent-protected LOKASIL 2[®] technology. It is a fact well-known from the machining practice that when large silicone precipitations are present in a aluminum-silicon alloy, they will be probably torn out from the material in the machining stage.

The process of large silicone precipitations cracking and tearing out will be also the cause of excessive abrasive wear and seizing of the sliding node. Developing a microstructure of hypereutectic alloys optimal from the point of view of eliminating the phenomenon of seizing, is the subject of interest in numerous scientific centers [14]. Fine silicone precipitations, more favorable as far as avoidance of seizing is concerned, can be obtained by means of modification of the liquid metal as well as by accelerated cooling in the alloy solidification phase. It may prove to be a particularly interesting solution to use for this purpose such unconventional technique as remelting the casting surface by means of concentrated stream of heat from a laser beam [15] or electric arc plasma [16, 17]. One may expect interesting effects from plasma spraying applied to obtain a gradient coating of e.g.

NiAl + Al₂O₃ or applying a plasma-sprayed coat using a powder prepared from a Al-Si alloy, containing e.g. 30% Si.

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