Development of Aluminium Alloy Composites for Engine Cylinder Application

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Abstract— This paper presents a short summary of the researches conducted in past few years concerning the MMCs with A356 Al-Si alloy matrix and different second phase. The results are divided in two groups. In the first group are the results that concern the influences of amount and size of reinforcement (Al2O3), and in the second group are the results that concern the influences of type of reinforcement (Al2O3 and SiC) and graphite

Key words: Cast iron, Engine blocks, Cast Iron Alloys, Aluminium Casting Alloy

I. INTRODUCTION

Aluminium-silicon (Al-Si) alloys have attractive physical and mechanical properties. They are lightweight (app. 3x lighter then gray cast iron and steel), low costs production (with sand casting technology), easy to machine and have satisfactory mechanical properties with good recycling possibilities (up to 95%). There are lots of applications of the Al-Si alloys, and one of them is replacing gray cast iron in engine cylinder blocks. Use of Al-Si alloys in this application has positive and negative aspects. Positive aspects are: reduction of engine mass, lower fuel consumption and reduced pollution; Shortcoming is, first of all, inappropriate tribological properties. Possible solutions for improving the Al-Si alloy tribological characteristics are: use of the tribological coatings, development of the new technologies of Al-Si alloys production (e.g.thixoforming) and production of the MMCs with Al-Si matrix [1,2].

II. ENGINE DEVELOPMENT

Current diesel engine development has lead to further increased ignition pressures. This consequently results in higher strength and stiffness requirements for the engine block and puts high demands on the material of a cylinder head, e.g. in the combustion chamber. Furthermore, in an engine block, high temperatures occur ranging up to the maximum oil temperature of about 150°C and even higher in the interbore spacing. Both during engine block assembly and engine operation high static loads prevail superimposed by alternating or cyclic stresses due to combustion and crankshaft rotation. This leads to high cycle fatigue on the flame-deck of a cylinder head and in the crankshaft bearings of the blocks respectively. The economic and ecological demands for fuel-saving, light-weight engines led to the use of aluminium cast alloys for almost all cylinder heads and increasingly for blocks as well. Even new diesel engine blocks are now on the way being designed in aluminium. For the aforementioned reasons an optimum aluminium alloy for engine block application has to fulfill several, partly counteracting, requirements:

– high strength and creep resistance from room temperature to elevated temperatures (up to 150°C and more)
– high thermal conductivity
– low porosity
– good casting properties, low hot tearing tendency
– resistance to fatigue, i.e. high fatigue strength at elevated temperatures

To improve strength and creep properties, generally, alloying elements such as Mg and Cu are added. On the other hand all alloying elements which dissolve in the α-matrix or which will reduce the amount of α-dendrites will decreases the heat conductivity. Ductility can be increased by low iron contents which on the other hand increases the price for the alloy. Further contribution to higher ductility will be given by modification of the AlSi-eutectic by means of Na or Sr.

Unfortunately, the addition of the modifier elements is often associated with increased porosity, possibly through altered feeding efficiency or increased risk to gas pick-up of the aluminium melt. Casting properties are enhanced by increasing the Si content close to the eutectic composition and by maintaining a low Cu level in order to decrease the solidification interval. Many of the aforementioned measures may be acting positively for one requirement, but adversely for others. This means that a compromise has to be found to meet all requirements for an optimized combination. Previous alloy development work led to an optimized alloy for cylinder head castings based on an A356 base alloy with additions of 0.5 % Cu in order to increase strength and creep resistance at elevated temperatures while maintaining good ductility by means of a low Fe and Mn content [Feikus, 1997].

III. PROGRESS IN ALLOY DEVELOPMENT

Further progress in alloy development was made for engine block applications. In contrast to cylinder heads the block requires higher strength, but can sacrifice some ductility. Therefore, a new alloy was developed on the basis of the alloy AlSi7MgCu0.5. Based on a statistical design of experiments considering the elements Si, Mg, Fe, Cu, Ni, and Mn, an alloy of the type AlSi7MgCuNiFe was derived. This alloy has good high temperature characteristics and which can be considered as a secondary-alloy type owing to a higher Fe tolerance [Feikus, Heusler, 1999]. Besides the alloy choice, it should be emphasized that the mechanical properties of a casting, are strongly influenced by the microstructure which in turn is a result of the casting process and the cooling conditions. The achieved porosity levels and SDAS play an important role for good static and dynamic strength of an engine block. Recently, sand casting processes such as the Core-Package-System have been developed for the casting of engine blocks and cylinder heads allowing a high degree of part complexity

[Smetan, 1996]. Moulds from the CPS-process consist purely of PU-Cold-Box cores which permits a very high dimensional accuracy of the castings. As described in Fig. 1 the casting is gravity filled from bottom to top by contact pouring through the risers, which during the filling stage are underneath the casting. After mould filling is completed, the sand-core-package is rotated so that the risers are on top of the casting providing the hotest metal to feed the part. The CPS system also allows the mechanical properties to be tailored by selection of casting cavity orientation and the use of optional chill plates in the sand package. Depending on which part of the casting is intended to have the best mechanical properties the casting can either be filled (and fed) via the crankshaft bearing saddles and the crank case (oil-pan-flange) and chill-cooled on the joint-face or filled via the joint-face and chill-cooled on the bearings.

IV. SELECTING ALUMINIUM CASTING ALLOYS

supplement and provide greater depth to our technical explanations, we refer you to standard works on aluminium and aluminium casting alloys. Further details on other specialist literature are available and can be requested at any time. We would be delighted to advise you in such matters. Should you have any queries or comments, which are always welcome, please contact our technical service. Standard works on aluminium and aluminium casting alloys.

In the European DIN EN 1676 and DIN EN 1706 standards, the most important aluminium casting alloys have been collated in a version which is valid Europewide. Consequently, there are already more than 41 standard aluminium casting alloys available. Aluminium foundries should – according to their respective structure – limit themselves to as small a number of casting alloys as possible in order to use their melting equipment economically, to keep inventories as low as possible and to reduce the risk of mixing alloys. With regard to the quality of a casting, it is more sensible to process a casting alloy which is operational in use than one which displays slightly better properties on paper but is actually more difficult to process. The quality potential of a casting alloy is only exploited in a casting if the cast piece is as free as possible of casting defects and is suitable for subsequent process steps (e.g. heat treatment).Our sales team and technicians are on hand to provide foundries and users of castings with assistance in selecting the correct aluminium casting alloy.

V. CASTING PROPERTIES

Further selection criteria comprise casting properties such as the fluidity or solidification behavior which sets the foundry man certain limits. Not every ideally-shaped casting can be cast in every casting alloy. A simplified summary of the casting properties associated with the most important casting alloys is shown in Table 2.Co-operation between the technical designer and an experienced foundry man works to great advantage when looking for the optimum casting alloy for a particular application. Given constant conditions, the fluidity of a metallic melt is established by determining the flow length of a test piece. Theoretically, low fluidity can be offset by a higher casting temperature; this is however, linked with disadvantages such as oxidation and hydrogen absorption as well as increased mould wear. Eutectic AlSi casting alloys such as Silumin or Al Si12 display high fluidity.

Hypoeutectic AlSi casting alloys such as Pantal 7 have medium values. AlCu and AlMg casting alloys display low fluidity. Hypereutectic AlSi casting alloys such as Al Si17Cu4Mg occupy a special position. In their case, very long flow paths are observed. This does not however necessarily lead to a drop in the melt temperature since primary silicon crystals already form in the melt. The melt still flows well because the latent heat of solidification of the primary silicon

VI. CONCLUSIONS

The aluminum alloy hard particle composite can successfully be synthesized by solidification process (stir casting or vortex technique). Aluminium composite so developed exhibit uniform distribution of the particle in the matrix and good interface bonding between the ceramic phase and the metallic matrix. Aluminium composite provides higher wear resistance than those of the base alloys in all tribo-conditions. In case of high stress abrasive wear, the improvement is noted to be more at low load and finer abrasive size. Beyond a critical load and abrasive size, the composite exhibits more or less same wear rate to that of base alloy. Wear rate increases almost linearly with the applied load. Composites exhibit improved wear resistance and seizure pressure as compared to the alloy under both dry and lubricated sliding wear. Further, frictional heating and coefficient of friction are noted to be considerably less in composite as compared to that in the alloy.

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