MICROSTRUCTURE CHANGES OF PARTIAL RE-MELTING REINFORCED A319 ALLOY FOR DIESEL CYLINDER HEADS

M. Kitamura*, W-S. Liu*, S. Tohriyama*, T. Sato** and A. Kamio**

* ISUZU MOTORS LIMITED, 8 Tsuchidana, Fujisawa-shi, 252 Japan
** Department of Metallurgical Engineering, Faculty of Engineering of Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo, 152 Japan

ABSTRACT

Microstructures of A319 aluminum diesel cylinder head, which was reinforced by TIG re-melting method around the inter valve area, are investigated after actual engine durability test. Its microstructure changes are compared with separate soaking samples over 523K and also discussed in correlation with the result of thermo-mechanical fatigue test between 373K to 523K.

Keywords: *A319, re-melting, cylinder head, thermal fatigue*

1. INTRODUCTION

Aluminum castings are used widely for the weight reduction of vehicles and engines. Lightweight aluminum diesel cylinder heads, especially the combustion chamber face, are exposed under heavy loads and high temperatures. LPDC (Low Pressure Die Casting) process has good ability of feeding for complex and thin wall casting, and is used for gasoline as well as diesel cylinder heads. The casting is normally positioned chamber side down, same as GDC (Gravity Die Casting), for better core setting, causing poor quality cast structure at chamber side.

One of our authors clarified the dominant effect of DAS (secondary Dendritic Arm Spacing) on the number of cycles to fracture in thermo-mechanical fatigue on A319 and A356 alloys.

In this study, re-melting technique is utilized to improve DAS on the inter valve seats area of diesel cylinder heads, and after the completion of the so-called hot and cold test of engine durability, the valve seat area was investigated. We prepared separate samples for soaking. From the viewpoint of microstructure changes, the effects of re-melting on the thermal fatigue performance will be discussed

2. ACTUAL EFFECT OF ENGINE DURABILITY TEST ON MICROSTRUCTURE

Sample cylinder head casting was produced by LPDC, and re-melting treated on its inter valve seats bridge and between the seats and hot plug area, then T6 heat treatment followed. DAS was improved from 50~60 to ~10μm. After hundreds hours of engine durability test, inter valve seats bridges of cylinder head were cut out. Hardness of re-melting area, a few mm depth from combustion chamber face and exhaust valve side, was 56~65HV, whereas the hardness was 130 before the engine test. Operating temperature was estimated at 508~523K based on the hardness value. The fact of hardness decrease of 70HV or more during engine durability test indicates severe circumstances of aluminum diesel cylinder heads in operation.

3. EXPERIMENTAL RESULT OF MICROSTRUCTURE IN SOAKING

Because of very low hardness as shown in the previous section, fatigue softening in thermal fatigue test [1], plain soaking investigation was necessary to better understand thermal fatigue phenomena of specimen and real diesel cylinder head castings.

The chemical composition of alloys for soaking is given in Table 1. Cooling rate in solidification is another major factor for the material performance. DAS is an indicator of cooling rate, and the material with fine DAS which also means low amount of porosity, shows significantly improved mechanical properties, ultimate tensile strength, yield strength, elongation and consequently fatigue strength [1]. Fig.1 shows microstructure of soaking test samples before heat treatment. Another microscopic feature of re-melting specimen is the morphology of silicon. Fig.2 shows long eutectic silicon phase around 50 μ m, however, we can find silicon phase of re-melting area in the form of particles with only a few μ m diameter (Fig.3).

Table 1 Chemical composition of A319 alloy

Element	Cu	Si	Mg	Zn	Fe	Mn	Ti
Mass %	3.1	7.2	0.2	0.01	0.10	0.02	0.003

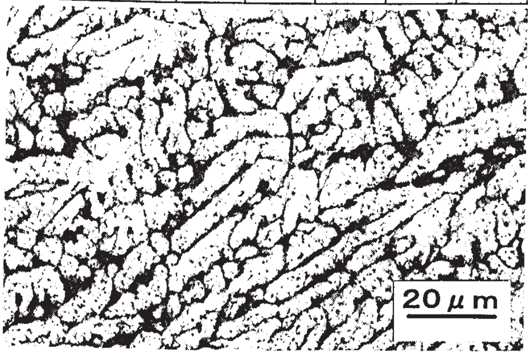

Fig.1 Microstructure of area with re-melting : DAS 6∼10 μ m

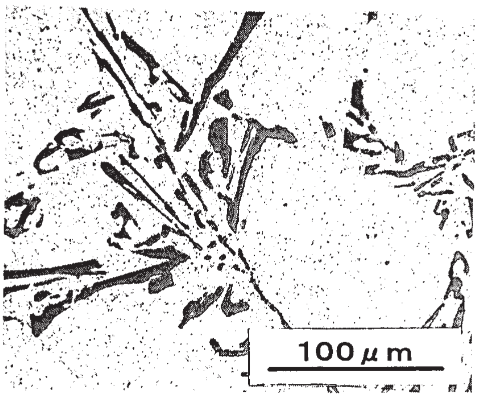

Fig.2 Microstructure of area without re-melting (T6)

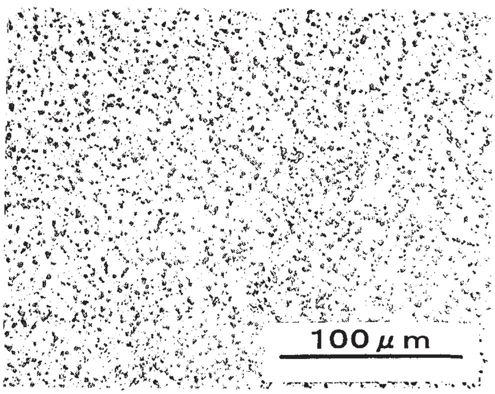

Fig.3 Microstructure of area with re-melting : DAS 6∼10 μ m (T6)

The hardness change with respect to soaking time is shown in Fig.4. After soaking for 24～32 hours at 523K, the hardness fell to a final value near 60HV. Another soaking trial of 32 hours at 548K gave the same value. We must note that the hardness value of combustion chamber face was 56～65HV after engine durability test.

In Fig.5, one can see Al_2Cu precipitates in white image, and some of them have cracks. Fig.6 shows that very fine Al_2Cu particles are distributed over the whole area.

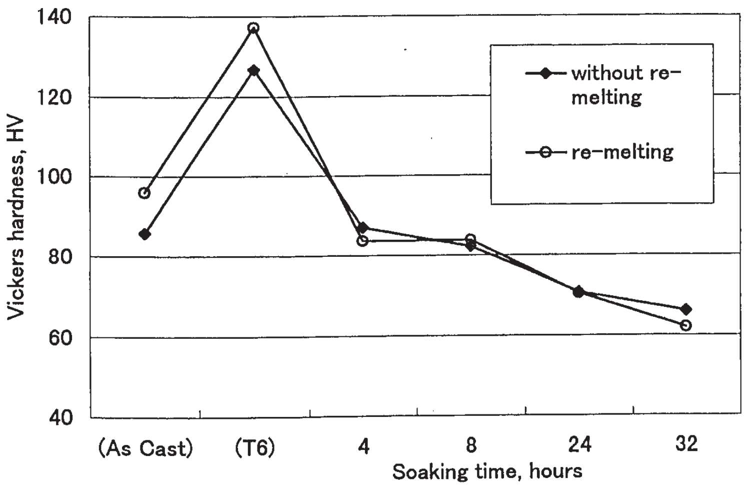

Fig.4 Hardness vs. soaking time curves

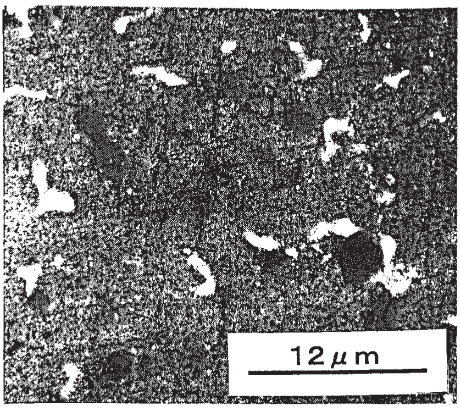

Fig. 5 Scanning electron micrograph of Si and Al_2Cu precipitates in re-melting specimen after soaking of 24 hours at 523K.

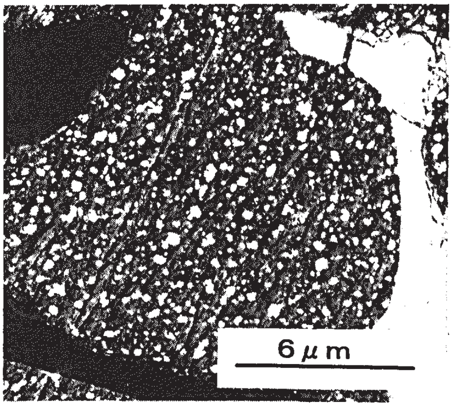

Fig. 6 Scanning electron micrograph of fine Al_2Cu particles in the specimen after soaking of 8 hours at 523K.

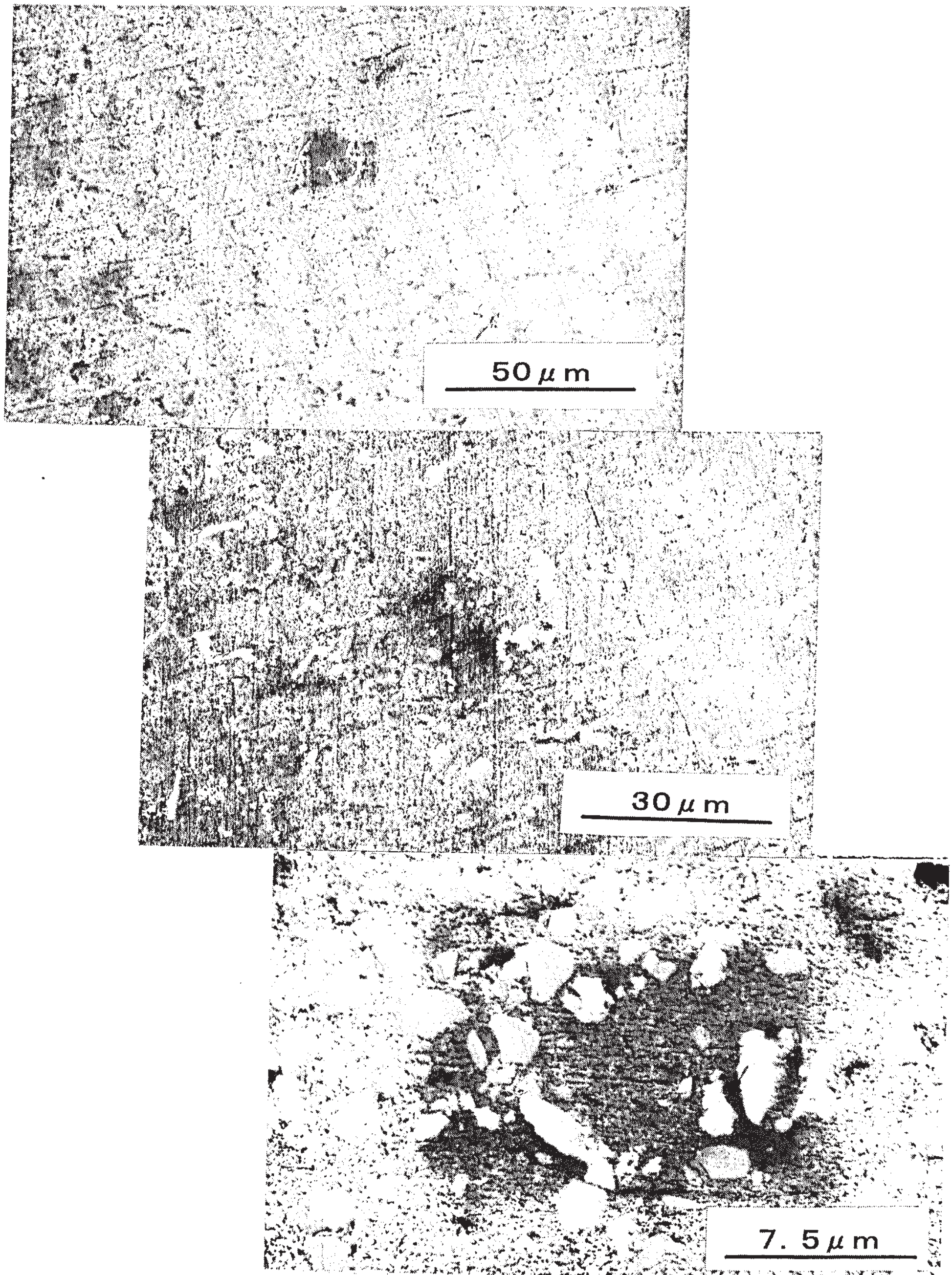

Fig. 7 Scanning electron micrograph of Si and Al_2Cu precipitates in the valve seat re-melting area of cylinder head casting after hot and cold engine durability test. Various magnifications show the distribution and detail of Al_2Cu compounds.

4. DISCUSSION

Cracking phenomenon was found in the microstructure both of actual cylinder head after the engine durability test (Fig. 7) and soaking specimen. Al_2Cu precipitates, θ, have grown to 5 μm or more, and also fine particles of 0.2~0.5 μm diameter were found throughout the whole place. Meyer took TEM picture of thermal fatigue test specimen with T64 temper, and showed that the average size of Al_2Cu precipitates is ~0.12 μm [2]. This diameter is too large to expect the hardness obtained from ordinary dispersion hardening. In Fig.5, the specimen with thermal effect only, we can observe cracks in the Al_2Cu precipitates. These precipitates are considered to be more stable at high temperature than other hardening phases such as Mg_2Si. However, in severe conditions of over 523K, the presence of the phase may not enhance the performance but has a detrimental effect on the material as a crack initiator and propagation passage.

As shown in Fig.8, re-melting specimen achieved 500 cycles of thermal fatigue tests, without re-melting specimen barely reached 15 cycles at $1/2\Delta\varepsilon_t$ (total strain range), between 373K to 523K. This improvement could be explained by the modification to fine structure of Si and Al_2Cu. In most cases, copper addition is considered to raise the high temperature strength in aluminum alloys [3], but for temperatures around 523K, which is the operating range of diesel cylinder heads, careful size control of Al_2Cu phase is necessary to increase the thermal fatigue life.

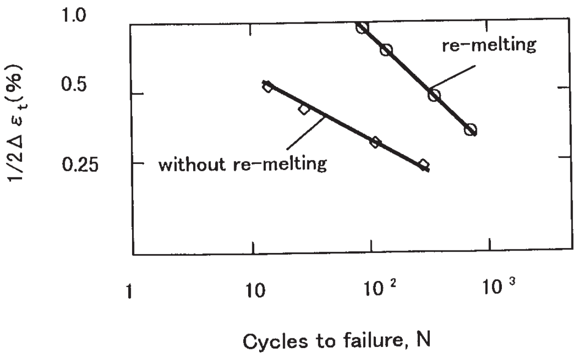

Fig.8 Results of thermal fatigue tests: A319-T6

5. CONCLUSION

1. TIG re-melting increases HV hardness by 10 in both as cast and T6 heat treated castings.
2. Comparing the microstructure of actual aluminum diesel cylinder heads with soaking test castings, coarsening and cracked Al_2Cu compounds were observed in both castings. This compound plays a major role in thermal performance, and consequently thermal fatigue performance in A319 alloy.

3. Re-melting process changes both Al_2Cu compounds and eutectic Si phase to extremely fine particles, causing a dramatic improvement of thermal fatigue life.

6. REFERENCES

[1] S. Tohriyama & M. Kumano, SAE Technical Paper No.950720, International Congress and Exhibition, Detroit, Michigan, 1995

[2] Ph. Meyer, D. Massinon, Ph. Guerin & L. Wong, SAE Technical Paper No.970705, International Congress and Exhibition, Detroit, Michigan, 1997

[3] R. Chuimert & M. Garat, Internationales symposium "aluminum + automobil" Dusseldorf, 1988