CYLINDER HEAD RESEARCH INVESTIGATION

The following investigation and report into the effects of heat on aluminium alloy cylinder heads, was undertaken by Dr. Edward Clansey of Clansey Metallurgical, Auckland, New Zealand, on behalf of AA Gaskets Pty Ltd.

Dr. Clansey holds the following qualifications:

PhD - Doctor of Philosophy (Metallurgy)
MsC - Master of Science (Metallurgy)
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BACKGROUND

Recently emerging problems with cylinder heads and gaskets prompted AA Gaskets Pty Ltd to look into the possibility that the heating of cylinder heads, which is carried out by engine reconditioners as part of the normal reconditioning process, is having an adverse effect on the subsequent gasket performance.

In view of this, it was decided to carry out the following investigational work:

a. On New Heads

1. Test and record hardness;
2. Heat heads in 50 degrees stages, from 150 to 350 degrees Celsius, and record hardness after each stage.

b. On Used Heads

1. Test and record hardness;
2. Identify the material type by chemical analysis;
3. Report on material type by chemical analysis;
4. Straighten;
5. Re-test.

Note: Hardness tests to be carried out on the head face and also the bolt bosses.

The results of the work were as follows:

CHEMICAL ANALYSIS

Chemical analysis was carried out on two used heads only, one from a Mitsubishi and one from a Mazda. The results were:

	Mitsubishi	Mazda
Silicon	8.30	8.49
Iron	0.60	0.69
Copper	3.64	2.76
Magnesium	0.30	0.15
Zinc	0.70	0.69
Nickel	0.07	0.08
Manganese	0.33	0.36
Chromium	0.03	0.05
Titanium	0.11	0.07
Aluminium	Remainder	Remainder

Although there were noticeable differences between the two analysis, they both conformed to the Japanese aluminium alloy die casting ADC 10 specification, which is a standard alloy used worldwide for the die-casting of cylinder heads. Equivalent national specifications are:

A.S.T.M. A.380; ISO R. 164; Al-Si 8 Cu 3 Fe; B.S. 1490 LM 24; DIN 1725 GD AlSi 8 Cu 3; AS313.

This alloy is used in the die-cast condition, and is generally considered to be a non heat-treatable alloy. i.e. it does not respond to solution treatment and precipitation hardening.

HARDNESS SURVEY

All testing was carried out on a Rockwell hardness tester. The results are in Rockwell "B".

Condition	**Position**	**Mitsubishi 4G63**	**Mazda FE**
NEW			
As received	Head Face	48/53	70/73
	Bolt boss	48/55	71/75
150 deg. C.	Head Face	40/46	70/78
	Bolt boss	40/45	70/75

Condition	Position	Mitsubishi 4G63	Mazda FE
200 deg. C.	Head Face	47/49	67/69
	Bolt boss	52/55	68/77
250 deg. C.	Head Face	36/38	45/49
	Bolt boss	40/43	50/57
300 deg. C.	Head Face	25/30	18/22
	Bolt boss	28/33	21/25
350 deg. C.	Head Face	8/10	4/6
	Bolt boss	8/12	12/14
USED			
As received	Head Face	50/54	48/53
	Bolt boss	60/62	58/63
After str.	Head Face	48/53	47/51
	Bolt boss	63/67	55/67
+ 290 C.	Head face	22/25	22/25
	Bolt boss	30/35	22/25

Notes:

41 Rockwell "B" is as low as the commonly used charts record. This is approximately equivalent to 81 Brinell. The lowest hardness level normally experienced with aluminium alloys is 30 Brinell.

A Brinell hardness tester was not available for the testing of these heads. Whilst the Rockwell "B" test should not be used at these low levels of hardness, the results still give a useful indication of the response of these heads to high annealing temperatures. However, the actual figures recorded must not be considered absolute.

The testing was carried out on the head face and the bolt boss for each casting. At each of the annealing temperatures the heads were soaked for one hour, followed by cooling in still air. Several hardness tests were carried out in each position after each annealing operation. The highest and lowest results were discounted and the range of the remaining results recorded.

As well as being recorded in tabular form, the results were also displayed graphically - see the attached graph. This clearly illustrates the pronounced softening which occurs on both head types at temperatures above 200 degreesC. The Mazda head dropped more than the Mitsubishi, but this was primarily because of its higher initial hardness. This high initial hardness was probably the result of rapid cooling after die casting, followed by some degree of natural ageing.

From purely chemical evidence, it would have been expected that the Mitsubishi head would have been harder than the Mazda head as a result of the higher copper and magnesium levels, but obviously the foundry practice overcame the chemistry factors. These factors were, however, apparent after annealing at the higher temperatures, with the Mazda head dropping to a lower level of hardness.

The graph also demonstrates that at 200 degrees C., the Mitsubishi head exhibited a mild increase in hardness over its hardness after the 150 degrees C. annealing. This would indicate a limited ageing response.

The straightening process which, reportedly, was carried out after heating to 280/300 degrees C., did not soften the heads as much as the experimental annealing treatment on the new heads. In view of this, both of the straightened heads were re-annealed at 290 degrees C., with a one hour soak, followed by re-testing - see the above table for the results. Note the pronounced drop-off in hardness on both heads.

MICROEXAMINATION

In view of the slightly unexpected hardness results when compared with the chemical analysis, it was decided to carry out a microexamination on both heads. To this end, a microsection was prepared from the side wall of each head. The section thickness at the sample point was different, with the Mazda being approx. 4mm, and the Mitsubishi being approx. 7mm.

Both exhibited similar, though not identical, structures, consisting of primary "alpha" dendrites in a eutectic matrix. In addition, secondary intermetallic compounds were also present, including Mg Si, Cu Al and also an iron-rich intermetallic in blade-like form. These features are reasonably typical of such die casting alloys. The Mitsubishi head showed no evidence of modification, whilst the Mazda head had undergone a modification treatment. This resulted in the Mitsubishi structure being considerably coarser than the Mazda.

COMMENTS

This investigation confirmed that both manufacturers manufacture their heads from similar material, conforming to the Japanese die casting ADC 10 specification. This is very similar to the UK, USA, and European cylinder head die casting alloys. Slight chemical and casting variations resulted in a different response to annealing, but essentially the end results were similar i.e. any temperature above 200 degrees C. softens the heads, and temperatures of 300 degrees C. and above greatly soften the heads.

The additional experiment of re-annealing after the straightening operation, also resulted in a marked drop-off in hardness. This proved that the temperature of the annealing carried out prior to the straightening operation was considerably lower than was believed. This may be fortuitous as the reduction in hardness currently being achieved during the straightening sequence is considerably less than when annealed at a controlled 290 degrees C. in the heat treatment shop.

Any softening of the heads during the straightening sequence is undesirable, but if softening of the order experienced in this series of tests actually occurred in practice, then major problems would ensue. The tightening torques of the cylinder head bolts would be incorrect, and, in addition, the heads of the bolts would dig into the head, making accurate tightening impossible. The practice of using a steel washer under the heads of the cylinder bolts would reduce, but not eliminate, this problem.

AA Gaskets have every reason to be concerned with these findings, as there is little doubt that gasket performance would be adversely affected by the head softening which occurs at annealing temperatures. The only saving grace is that, in the case of the used heads straightened in this exercise, the actual temperature achieved prior to the straightening was appreciably lower than was believed, which resulted in considerably less softening than would otherwise have been the case.

What AA Gaskets can actually do about this is not clear, but certainly an education programme for the engine reconditioners should be at the top of the list.

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