OTTAWA September 25th, 1940.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 898.

Examination of Six Defective Aluminium
Alloy Forgings.

BUREAU OF MINES
DIVISION OF METALLIC MINERALS

ORE DRESSING AND
METALLURGICAL LABORATORIES

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
MINES AND GEOLOGY BRANCH

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Origin of Material and Object of Investigation:

On September 20th, 1940, Mr. T. H. Blake, Inspector-in-Charge, B. S. B., Ottawa Car and Aircraft Limited, Ottawa, Ontario, brought in six aluminium alloy forgings, two being T-shaped, two Y-shaped, and two star-shaped. These forgings had been made by Hayes Limited for the Fort William plant of the Canadian Car and Foundry Co. Ltd. The inspector at this plant reported that cracks were being found in the T- and Y-shaped forgings and asked that Mr. Blake submit typical forgings for examination with the object of determining the reason for the cracking. As the Ottawa Car and Aircraft Limited were also experiencing the same trouble with the star-shaped castings, they submitted two of this type for a similar examination.

Macro-Examination:

Several of the forgings submitted had very fine cracks running along the flash line. All forgings appeared to have had a fairly large amount of flash metal, as the trimming die cut was fairly thick in every case. Data obtained from the forgings are listed below. The laboratory numbers given in the table will be used in future reference to the forgings.

Laboratory No.	Forging No.	Identification No.	Specification.	Forging type.
1.	A 284	HR 154	-	T-shaped.
2.	A 284	72B	-	" "
3.	A 572	HR 143	17 S	Y-shaped.
4.	A 572	HR 147	17 S	" "
5.	A 190	68B	-	Star-shaped.
6.	A 190	64B	-	" "

Chemical Analysis:

Drillings were taken from one sample of each

(Chemical Analysis, cont'd) -

forging and analysed. The following results were obtained:

Forging No.	Copper, per cent	Manganese, per cent	Silicon, per cent	Magnesium, per cent	Iron, per cent
A 284	4.55	0.67	0.56	0.56	0.31
A 572	3.55	0.56	0.38	0.49	0.56
A 190	3.55	0.56	0.38	0.48	0.56

Physical Tests:

Vickers hardness tests, using a 10-kilogram load, were made on all specimens. Small tensile test specimens were cut from the vertical portions of the T-forgings, from one of the arms of the Y-forgings, and from one of the prolongations of the star forgings. These test specimens were broken in an Amsler Universal testing machine. The following table gives the results of the physical tests. No proof stress results are listed as it was not possible to obtain these values from such small specimens.

Laboratory No.	Forging No.	Ultimate stress, p.s.i.	Elongation, p.c.	Diameter (in.)	Gauge length, inches.	Vickers hardness No.
1	A 284	57,600	19.0	0.284	1.0	112
2	A 284	62,800	8.0[@]	0.282	1.0	120
3	A 572	55,200	23.0	0.280	1.0	114
4	A 572	56,000	19.0	0.282	1.0	114
5	A 190	57,900	14.0	0.125	0.44	114
6	A 190	55,700	16.0	0.125	0.44	112

[@] Broke at gauge mark.

Microscopic Examination:

Specimens were cut from each forging and examined under the microscope. All forgings contained about the same number of light grey inclusions. The inclusions in Forgings 4 and 5 seemed somewhat smaller than those in the other samples. Etching tests identified these inclusions as being the copper-iron-manganese-aluminium constituents. Forgings 1 and 2 also contain some particles of pinkish-tinged $CuAl_2$. Figure 1, a photomicrograph at X500 magnification, was obtained from the sample taken from Forging 1. It may be seen that this forging shows some grain boundary fusion and also small rosettes of eutectic within the grains.

All specimens were then etched in Keller's reagent (1 part hydrofluoric acid, 1.5 parts hydrochloric acid, 2.5 parts nitric acid, and 95 parts water) and re-examined. The white etching rosettes in Forging 1, the white etching $CuAl_2$ compounds in Forgings 1 and 2, and the dark etching copper-iron-manganese-aluminium particles in all forgings were again evident. The etching revealed that all forgings with the possible exception of Forging 6 were fairly large-grained and that Forging 2 was mixed-grained, there being some very coarse-grained areas in the vicinity of the flash on this forging. These facts are demonstrated by Figures 2 to 8, which are all photomicrographs at X500 magnification.

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DISCUSSION OF RESULTS:

Macro-Examination -

The cracking at the flash line and the apparent large amount of flash material that was removed indicate that cracking may have occurred as a result of a straining of the forging in the trimming operation. Worn forging dies might account for the heavy flash; worn trimming dies for the distortion in trimming.

Chemical Analysis -

The compositional requirements of Department of National Defence Specification 6-L-1, governing the production of small aluminium alloy forgings, are as follows:

Copper, per cent	Manganese, per cent	Magnesium, per cent	Silicon, per cent	Iron, per cent
3.5 - 4.5	0.4 - 0.7	0.4 - 0.8	0.7 max.	0.7 max.

The compositions of the three forgings examined are within these limits. Forgings A 572 and A 190 appeared to have been poured from the same melt.

Physical Tests -

The Department of National Defence Specification 6-L-1 requires that aluminium alloys for small forgings shall have an ultimate tensile strength of 56,000 pounds per square inch, with an elongation of 15 per cent. With the exception of the elongation value for Forging 2, which is not representative as the specimen broke on the gauge mark, the physical properties reported for the forgings are very near the specified values. Making allowance for the use of small specimens, the results can be considered as being just satisfactory.

(Discussion continued on next page)

(Discussion of Results, cont'd) -

Microscopic Examination -

The inclusion content in all samples is normal. In the light of their fairly high copper content, the presence of $CuAl_2$ particles in Forgings 1 and 2 is to be expected. The grain boundary and rosette fusion in Forging 2 indicate that the metal was burned. This forging was probably heated to a temperature of nearly 1000° F. at some stage in its forming or heat treatment.

The fairly large-grained samples must have been forged at a fairly high temperature, as the grain size becomes smaller as the temperature at which the forging was finished is lowered. Forging 6 was probably formed at the proper temperature. The mixed grain size in Forging 2 indicates that this forging was cold worked in trimming, for the large grains are associated with the flash line, and grain growth will not occur in the absence of cold work.

General Remarks -

Aluminium alloys are usually forged around 850° F. The safe forging range is quite narrow, forming at much above or much below 850° F. resulting in cracking caused by hot shortness. Burning can only occur as a result of serious overheating. The examination would show that Forging 1 received such treatment. Burning in this casting must have been very slight, however, as its physical properties are satisfactory. An alloy can fail due to hot shortness without being burnt, for it is hot short at a temperature usually employed for the final

(Discussion of Results, cont'd) -

General Remarks, cont'd -

solution heat treatment and cannot be worked at this temperature. A forging, then, may be cracked as a result of forging at an improper temperature and, with the exception of the crack, still be in good condition after the final heat treatment. Forging at too high a temperature may result in a coarse-grained forging if the original stock was coarse-grained. An article may, however, be partially formed in the hot short range and finished at a temperature low enough to ensure the production of a fine-grained article. It is difficult to prove, then, whether a crack is produced as a result of hot shortness in forging. In the absence of any other satisfactory explanation it is reasonable to assume that hot shortness was responsible for the cracking. In this examination the metal apparently is satisfactory. The indications are that the parts were formed at too high a temperature. This is partially supported by the fairly coarse grain size of five of the forgings.

Conclusions:

The examination reveals that the metal was in good condition and consequently indicates that cracking was probably caused by forging at too high a temperature. The wide shear mark and the coarse grain structure at the flash line of Forging 2 indicate that strains set up in trimming may have been responsible for the

(Conclusions, cont'd) -

crack. Worn forging and trimming dies could possibly be responsible for the production of conditions that might lead to the straining of the forgings.

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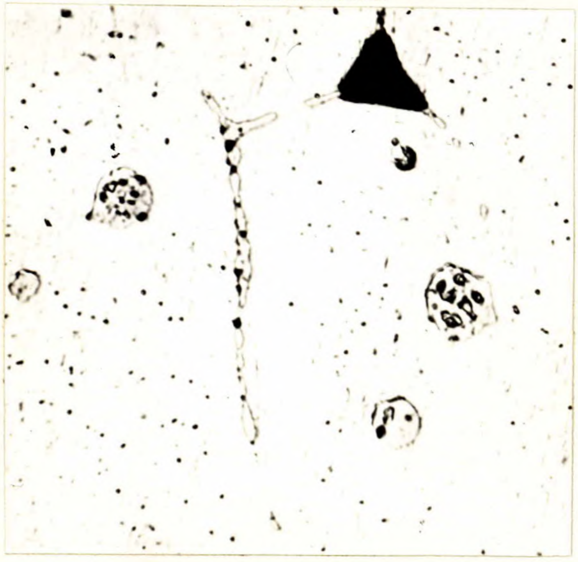
GSF:PES.

Figure 1.



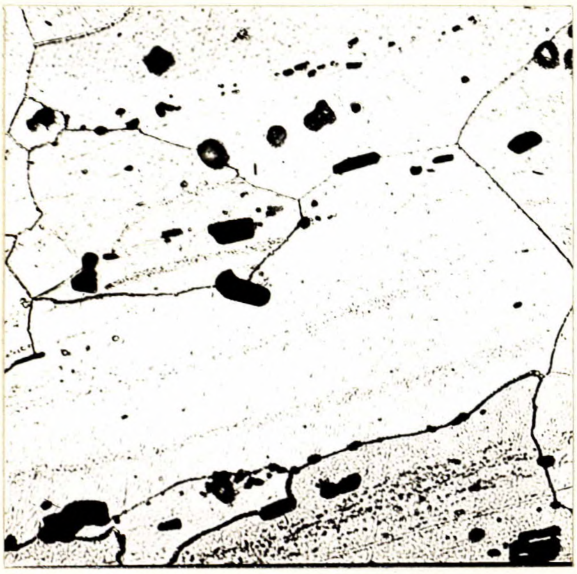
X500.

Forging 1. Unetched.

Figure 2.

X500.

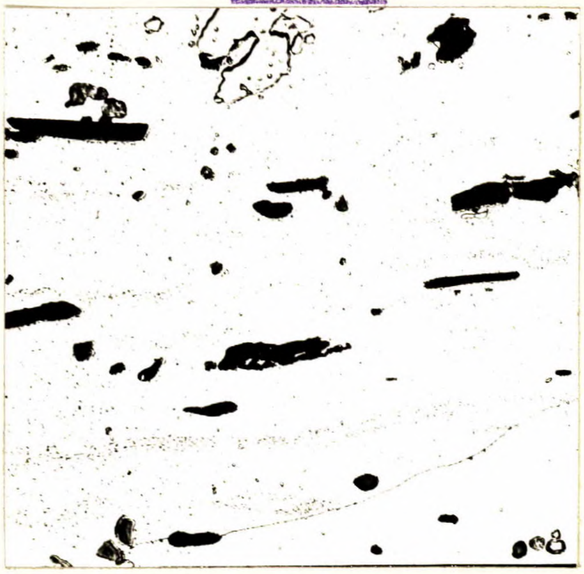
Forging 1, etched in Keller's reagent.



X500.

Forging 2. Finer-grained portion, etched in Keller's reagent.

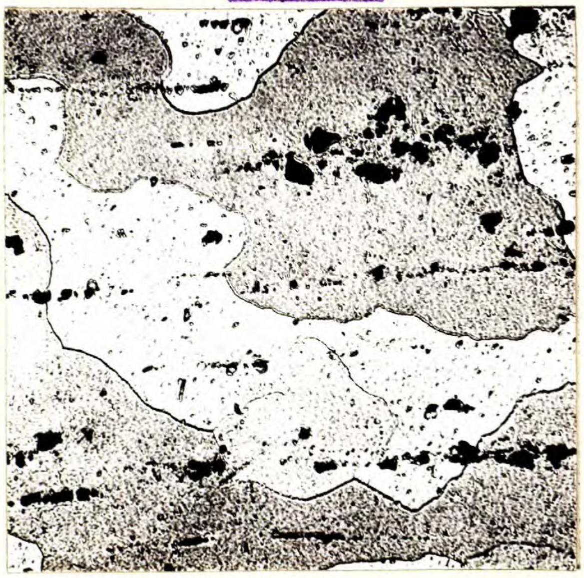
Figure 4.



X500.

Forging 2. Coarse-grained area near flash line, etched in Keller's reagent.

Figure 5.



X500.

Forging 3, etched in
Keller's reagent.

Figure 6.

X500.

Forging 4, etched in
Keller's reagent.

Figure 7.

X500.

Forging 5, etched in
Keller's reagent.

Figure 8.

X500.

Forging 6, etched in
Keller's reagent.

GSF:PES.