REINFORCING AGE HARDENABLE Al-Cr MATRIX ALLOY IN-SITU AND BY SiC/Al_2O_3 PARTICULATES

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Abstract

The achievable high ductility value of Al-Cr alloys (over 35% total elongation) has led to the attempt to produce in-situ composites with Al-Cr solid solution as the matrix phase and excess insoluble intermetallics $CrAl_7$ as the reinforcing constituent. The alloy produced with 1.20 wt% Cr results in in-situ composites which gives a good combination of high tensile strength and ductility (approx. 30% elongation). Composites based on Al-Cr matrix alloy with SiC or Al_2O_3 as the reinforcing phase showed that the increase in strength is quite considerable even at a relatively good ductility.

Introduction

The sloping nature of the solvus curve in the phase diagram of Al-Cr binary alloy system has led to considerable studies on the probable age-hardening behaviour in this alloy system [1-3]. It is reported earlier [2] that in Al-0.5 Cr alloy the precipitation of chromium aluminides takes place at the lattice defects and that there are two different types of precipitate morphologies seen in the alloy when aged at different temperatures. Chromium is known to have a tendency to form large sized intermetallics with aluminium, making the system quench sensitive [4,5]. It is also reported that trace additions and/or cold working before ageing can have significant influence on the ageing behaviour of a number of aluminium alloys [6]. Moreover the above alloy is known to posses a very high corrosion and oxidation resistance [2,7]

On the basis of available report on the effect of silicon in reducing the quench sensitivity of Al-Cr alloy it appears possible to develop Al-Cr-Si alloys with good age-hardenability. In the present investigation, attempts are made to optimise the composition of the ternary Al-Cr-Si alloy in terms of its age-hardening response.

In view of the recent interest in the development of metal matrix composites based on age-hardenable matrix alloys, it seems to be of worth to make use of above mentioned Al-Cr alloy as the base alloy to produce SiC/Al_2O_3 particulate reinforced composites that inherit the high corrosion and oxidation resistance and becomes moderately strengthened at a high ductility level by the reinforcing phases.

From the phase diagram of Al-Cr binary alloy system it appears that there is a possibility to get a mixture of two phases, viz. liquid and $CrAl_7$ at a moderately high temperature when the chromium concentration exceeds the primary solubility limit. Therefore, the solidification of this two phase mixture gives rise to a solid solution and $CrAl_7$ intermetallics embedded within the solid solution. This envisages the formation of in situ composites based on age-hardenable Al-Cr alloys. Hence in the present investigation the possibility of developing in situ composites based on corrosion resistant age hardenable Al-Cr alloy is also explored.

Experimental Procedure

Binary alloys of aluminium and chromium were prepared by melting pure aluminium under suitable flux cover. Requisite quantity of aluminium and chromium powder, compacted green, were added to the melt at 750°C. The melts were allowed to become semisolid. It was then further heated to 850°C and held for 15 minutes under gentle stirring and then resolidified. Remelting was carried out to achieve uniformity in composition. Addition of silicon was done by mixing in required quantity while making the powder compacts.

The binary Al-0.6 wt% Cr alloy so produced was melted at 850°C and was mechanically stirred to form a vortex. In order to minimise the possible reaction between SiC and aluminium the particulates (SiC/Al_2O_3) were gradually added to the melt when its temperature was reduced to 800°C. After the addition, degassing was done and the melt was continued to be stirred so that preferential segregation of the particulates might be avoided. The melt was then cast to 13 mm x 25 mm x 250 mm plates.

The cast samples were hot rolled at 375°C. All hot rolled alloys were cut to suitable sizes and were solution treated at 600°C for 5 hours followed by quenching in iced brine. The samples were then aged at various temperatures for 90 minutes. The ageing hardness was measured in Rockwell hardness tester. Optical, scanning, transmission electron microscopy and DSC studies were carried out for structural characterisation. The mechanical properties of the alloy and the composites were evaluated in an Instron testing machine.

Results and Discusion

Ageing behaviour

The isothermal ageing curves of alloys 1,2,3 & 6 aged at 375°C are shown in Fig.1. It is noticed from the figure that the age hardening response is higher in Al-0.78 Cr alloy than the Al-0.63 Cr alloy. However when the chromium content exceeds the

solubility limit as in Al-0.90 Cr alloy (alloy 3), the ageing response is poor and the ageing curve exhibits an incubation period prior to age hardening in the alloy. However addition of silicon in alloy 2 is seen to have increased the ageing response in Al-0.90 Cr-0.60 Si alloy where no incubation period is noticed. Also addition of silicon by 0.20 wt% in Al-0.78 Cr and Al-0.90 Cr (alloys 4,5) effects a noticeable change in the ageing response of the alloys. Al-0.78 Cr-0.20 Si alloy is particularly good in respect of age hardening as its chromium content is less than the solubility limit (Cr <0.78%). It is observed from Fig.3 that further increase in chromium content in excess of its primary solubility limit alters the ageing behaviour of Al-1.20 Cr alloy quite significantly. This alloy contains considerable amount of intermetallics and may be treated as in situ composites where $CrAl_7$ is embedded uniformly in the matrix of α-Al-Cr solid solution. Due to quench sensitivity an incubation period of 210 minutes is seen in its ageing curve, though the hardness values of the in situ composite are higher at all ageing times, when compared with binary Al-0.63 Cr alloy.

Chromium is known to have strong binding energy with quenched-in vacancies [8]. As a result, the diffusion of chromium in aluminium is sluggish and hence precipitation hardening in Al-Cr alloy is difficult. When chromium content is high the amount of insoluble intermetallics is also high in the microstructure. The interfaces between these intermetallics and the matrix act as the sink for vacancies. In such cases the excess solute cannot precipitate so easily during cooling, rather there is the growth of existing insolubles to relieve the local supersaturation. Silicon improves age hardening response due probably to its stimulating effect on the nucleation of chromium aluminides. This helps in the nucleation of precipitates of smaller critical nucleus size. So incubation period is reduced.

Differential scanning calorimetry (DSC)

DSC study was undertaken to understand the influence of reinforced particulates on age-hardening / precipitation behaviour of the alloy system. DSC scan of the binary alloy (Fig.4) shows a weak exothermic peak at 335°C characterising the formation of ageing precipitate. However the DSC curve of the SiC reinforced with particulate composite shows the formation of peak to take place at a lower temperature viz. 315°C. It therefore appears that reinforcement of particulates in the matrix of age hardenable Al-Cr alloys helps to accelerate the precipitation reaction. A similar observation in SiC reinforced Al-6061 alloy is reported earlier [9]. It is surmised that due to the difference in the coefficient of thermal contraction of the particulates and that of the matrix, dislocations are produced around reinforcing particles. Since it is demonstrated earlier that the process of precipitation in Al-Cr alloy takes place heterogeneously at the dislocations [10], the acceleration of precipitation phenomenon in particulate reinforced composites is therefore accounted for by the fresh precipitation onto dislocations. This kind of behaviour has been common in a number of MMCs based on precipitation hardenable aluminium matrix alloy.

The area under the DSC peak is proportional to the amount transformation. The activation energy for the formation of precipitates in the present alloys is measured by following the technique used by the previous workers [11]. From such measurement a value of 240 kJ/mole is recorded as the activation energy for the precipitate formation in a binary Al-Cr alloy. This is quite similar to the activation energy of interdiffusion of chromium in aluminium in the binary alloy. This means that the precipitation in binary alloy is kinetically controlled by the diffusion of chromium in aluminium. On the contrary, the activation energy of precipitation in the composite is found to be 221 kJ/mole. This is to mean that dislocation aided nucleation is accelerated in the composite and so activation energy for precipitation of chromium aluminides is decreased.

Mechanical properties :

Mechanical properties of the alloy and the composites are listed in Table 2. It is known that the present alloy system age hardens through the formation of precipitates onto the dislocations [3]. When composites are formed in situ the dislocations are seen to have formed around the reinforcing intermetallics (Fig.6.). This is supposed to be due to the difference in co-efficient of thermal contraction between solid solution and the insoluble intermetallics. Fine precipitates are noticed to be formed on these dislocations. This has contributed to the yield stress of the alloy which is seen to be higher than the base alloy. Table 2 also shows that using as low as 10 vol% particulates for reinforcement, the yield strength of the Al-0.63 Cr alloy (base alloy) has improved considerably and the range of improvement is recorded to be from 50 to 100% of the yield stress value for the base alloy. This improvement in properties may be explained from the microstructures presented in Fig.7-8. It appears that reinforcement by particulates have created more nucleation sites for the ageing precipitates. The generation of dislocations has increased the precipitation density and therefore has contributed to the strength. In the in situ composites, however, the volume fraction of insoluble intermetallics has been less (~4-5 vol%) owing to its chromium content which exceeds the primary solubility limit rather marginally. However, it gives a clear indication that it is possible to develop a high strength, high ductility in situ composite based on Al-Cr alloy. In SiC reinforced composite the dislocation density around the reinforcing particle is higher than that in case of Al_2O_3 reinforcement due to the fact that the difference in co-efficient of thermal contraction between matrix and SiC is higher than that between the matrix and Al_2O_3. Owing to this the precipitate density is also found to be higher in SiC reinforced composites. This explains why the improvement in yield stress has been more in this case.

Conclusion

Al-Cr age hardenable matrix based in situ composite of high strength and duc-

tility can be produced by suitably controlling the chemistry of the alloy. Reinforcement of particulates (SiC/Al_2O_3 in this study) by even as low as 10 vol% can improve the mechanical properties significantly.

References

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Table 1
Chemical composition of the alloys (wt%)

Alloy	Cu	Fe	Mg	Mn	Ni	Si	Ti	Zn	Cr	Zr
1	0.001	0.21	0.003	0.006	0.001	0.08	0.008	0.002	0.63	0.003
2	0.003	0.19	0.003	0.004	0.002	0.13	0.004	0.002	0.78	0.001
3	0.001	0.25	0.004	0.005	0.001	0.09	0.019	0.001	0.90	0.004
4	0.001	0.21	0.003	0.004	0.001	0.20	0.007	0.003	0.77	0.003
5	0.002	0.18	0.008	0.003	0.002	0.19	0.009	0.003	0.90	0.001
6	0.001	0.20	0.007	0.004	0.001	0.60	0.008	0.003	0.78	0.003
7	0.002	0.19	0.006	0.003	0.001	0.76	0.007	0.003	1.20	0.001

Table 2
Mechanical properties for the experimental alloys
(aged at 450°C for 90 minutes)

Material	Yield Strength MPa	UTS MPa	Knoop Hardness (30 g load)	% El
Al-0.6Cr (base alloy)	55	115	22	36
Al-1.12%Cr (in-situ)	68	120	40	30
Al-0.6Cr+ 8 vol% Al_2O_3	76	135	35	25
Al-0.6Cr+10 vol% SiC	100	158	41	22

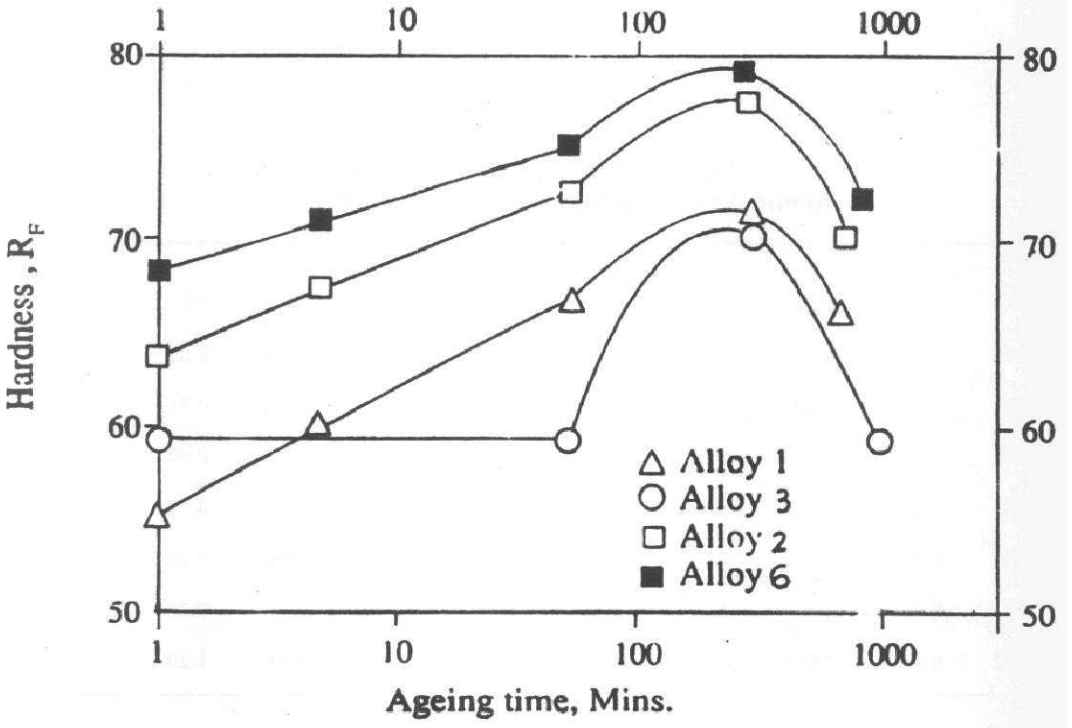


Fig. 1 - Hardness - time curves of the alloys aged at 375°C

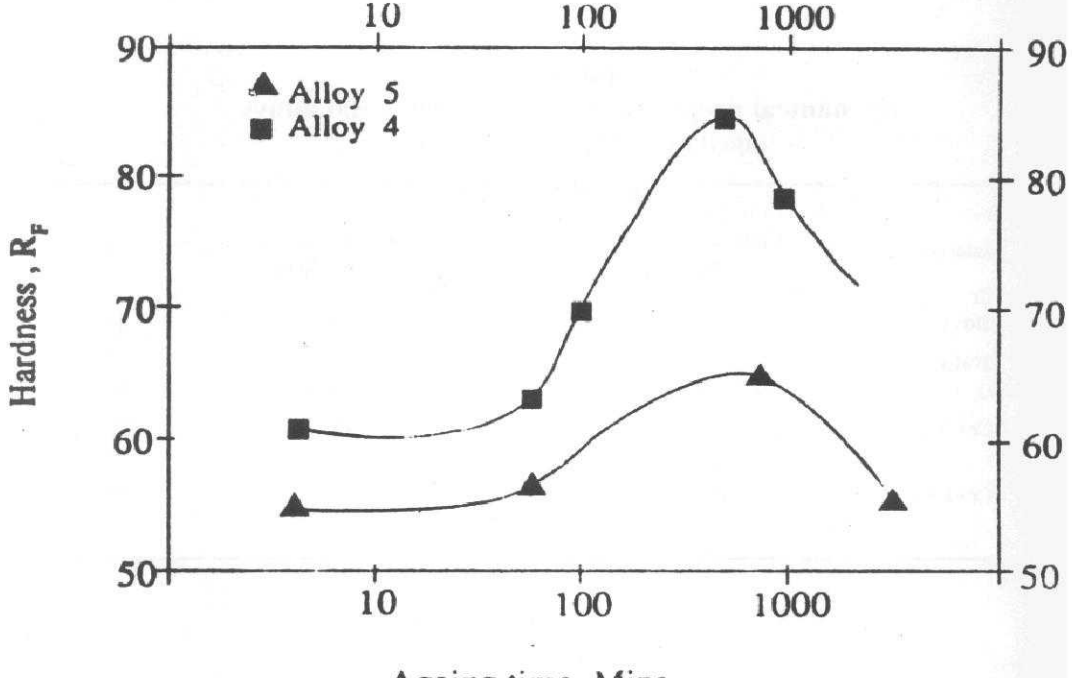


Fig. 2 - Hardness - time curves of the alloys aged at 375°C

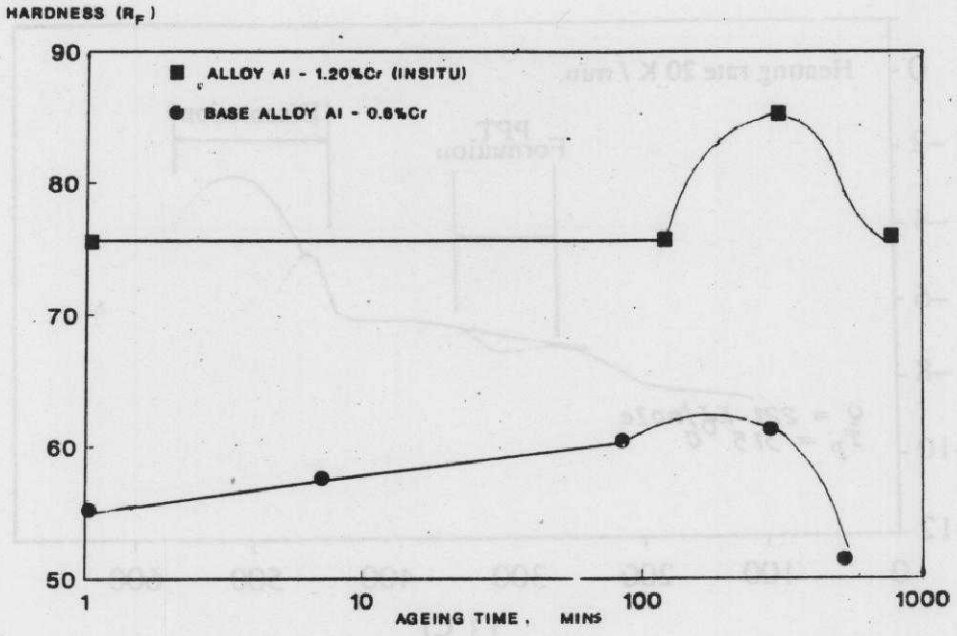


Fig. 3 - Hardness - time curve of the alloys aged at **375°C**

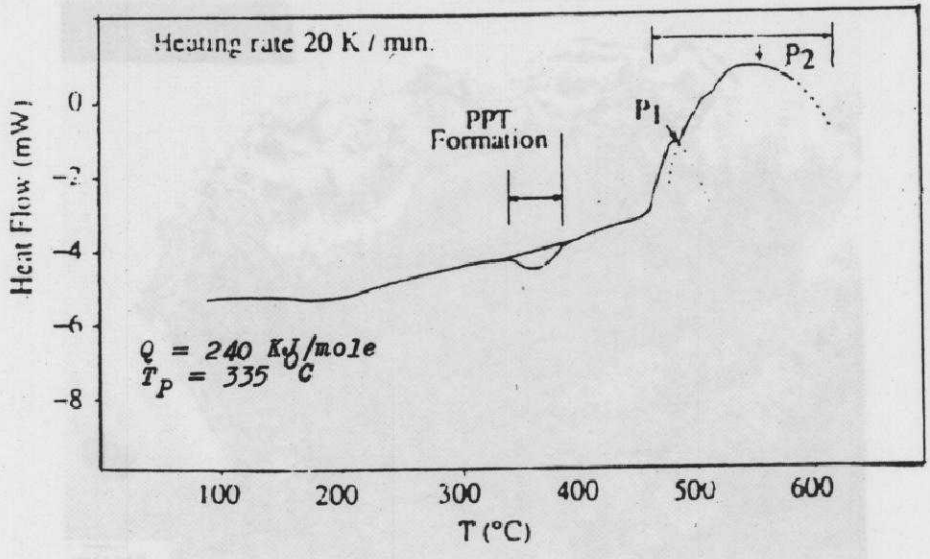


Fig. 4 - DSC response curve of binary alloy 1 heated from quenched condition

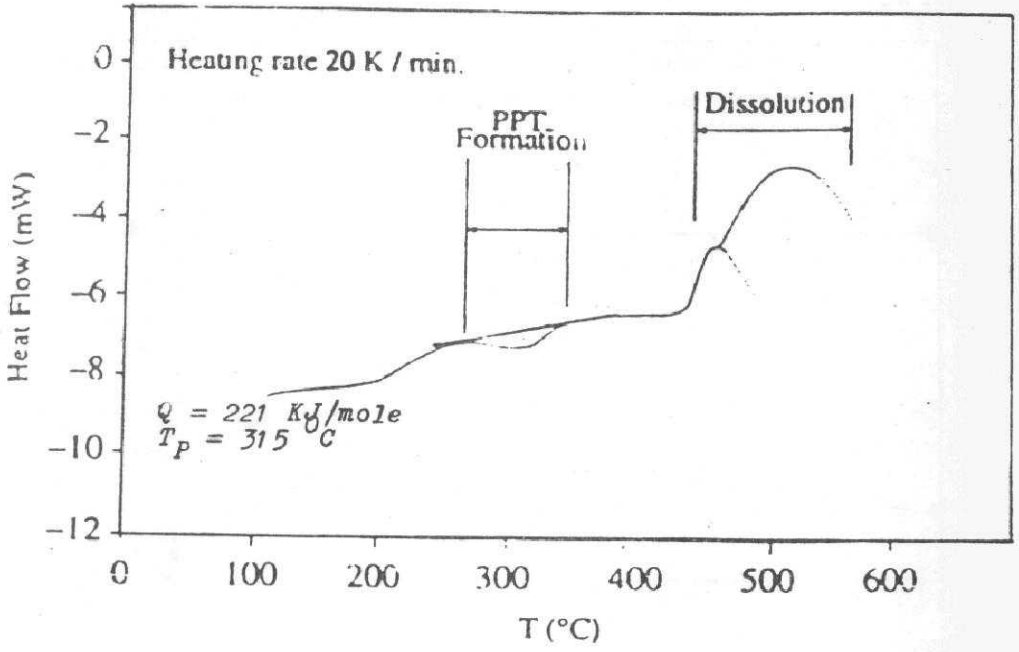


Fig. 5 - DSC response curve for the SiC reinforced alloy

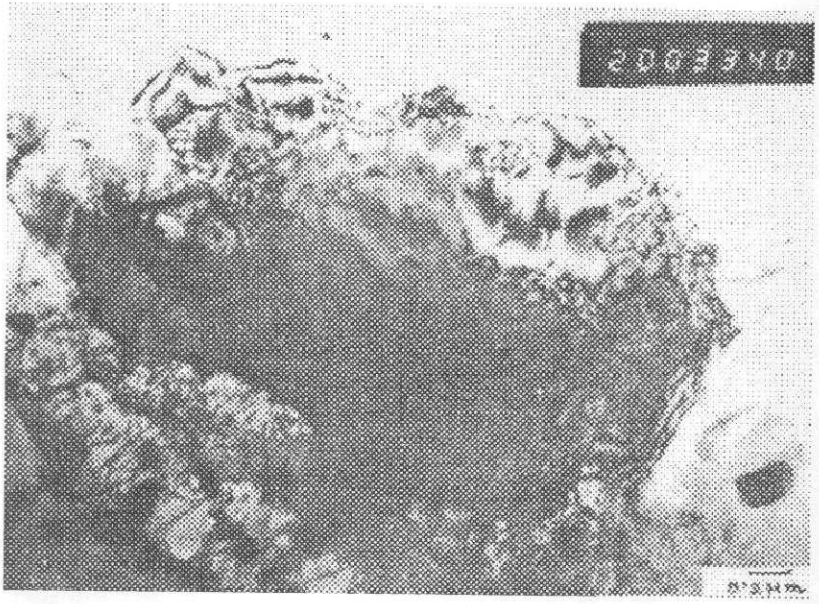


Fig. 6 - TEM micrograph of showing dislocations around reinforcing intermetallics.

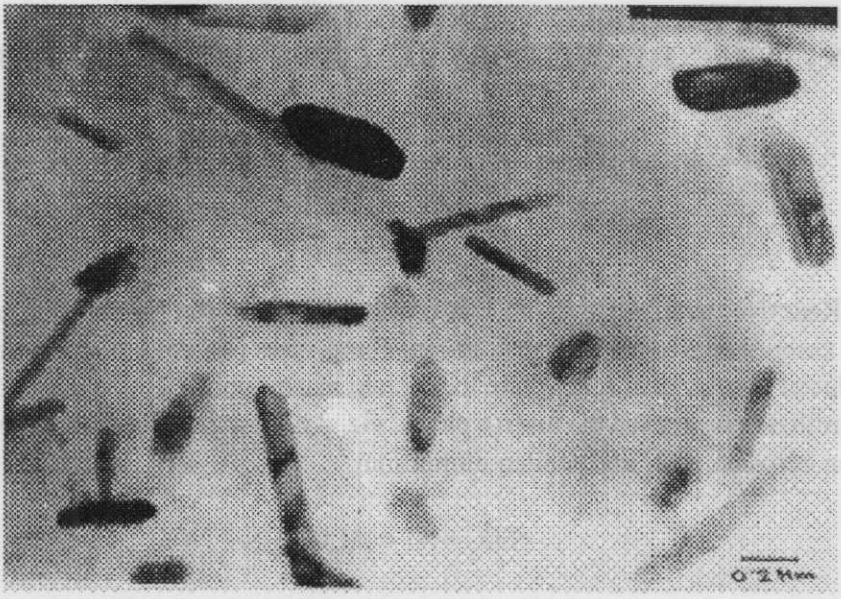


Fig. 7 - TEM micrograph of alloy 1, aged at 500° C showing rod type morphology of precipitates.

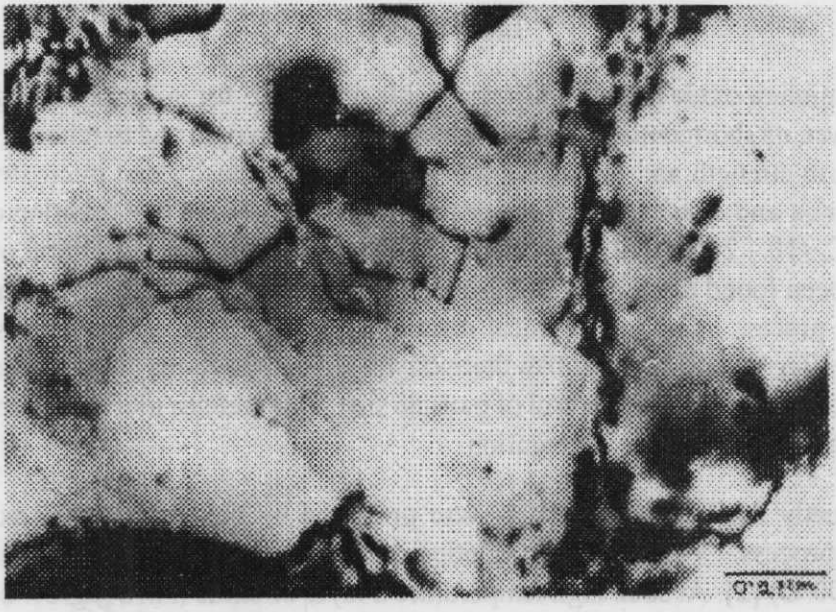


Fig. 8 - TEM of insitu composites, alloy 7, showing coarse aluminide particles, with dislocations observed at the particle/matrix interface promoting precipitation..