(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 716 716 B2

(12) NEW EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the opposition decision:
**29.12.2004 Bulletin 2004/53**

(45) Mention of the grant of the patent:
**12.08.1998 Bulletin 1998/33**

(21) Application number: **94924943.7**

(22) Date of filing: **30.08.1994**

(51) Int Cl.7: **C22C 21/02**

(86) International application number:
**PCT/GB1994/001880**

(87) International publication number:
**WO 1995/006759 (09.03.1995 Gazette 1995/11)**

# (54) Extruded Al-Mg-Si alloy section

Extrudiertes Profil aus einer AL-Mg-Si Legierung

Profilé extrudé en alliage Al-Mg-Si

(84) Designated Contracting States:
**AT BE CH DE DK ES FR GB IE IT LI LU NL PT SE**

(30) Priority: **31.08.1993 GB 9318041**

(43) Date of publication of application:
**19.06.1996 Bulletin 1996/25**

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## Description

**[0001]** This invention concerns intermediate strength extrudable Al-Mg-Si alloys, in the 6000 series of the Aluminum Association Register. The dilute Al-Mg-Si alloys, with levels of the two primary alloying additions at less than approximately 0.50 wt.%, are used extensively in extruded form in many market sectors, including architectural (doors, window frames, etc.) and structural applications. These alloys generally lie within the AA6063 specification, which has compositional limits for Mg and Si of 0.45 to 0.90wt.% and 0.20 to 0.60 wt.% respectively. These alloys are capable of producing complex sections which are readily air quenchable off the press and which may be extruded at high exit speeds whilst maintaining a very high quality surface finish; attributes which are associated with high extrudability.

**[0002]** EP 480 402 (A1) teaches a process for manufacturing an aluminium alloy material which has excellent formability in press working, shape fixability and bake hardenability. The alloys contain in weight %: Mg 0.3 - 0.5, Si 0.4 - 1.5 and optionally Cu, Mn, Cr or V.

**[0003]** The invention provides an extruded section of the following composition in weight % in which Fe is present as $\alpha$-AlFeSi

| | |
|---|---|
| Mg | 0.25 - 0.40 |
| Si | 0.60 - 0.90 |
| Mn | 0.10-0.35 |
| Fe | up to 0.35 |
| Others | up to 0.05 each, 0.15 total |
| Al | balance |

wherein the extruded section has after aging an ultimate tensile strength of at least 240 MPa.

**[0004]** Reference is directed to Figure 1 of the accompanying drawings, which is a compositional plot showing the Mg and Si specification ranges for various alloys in the Aluminum Association specification. The filled circle shows the nominal composition d alloys according to the present invention, and the rectangle round it corresponds to the above definition. It can be seen that the above defined alloy composition does not overlap with any of the AA designated alloys shown.

**[0005]** The alloys are high excess Si alloys. The nominal composition of these alloys (marked by the filled circle in Figure 1) is set out in the table below, together with the nominal compositions of AA6106 which is an excess Si alloy, and of AA6063A which is a balanced alloy. An alloy of balanced composition is one in which just enough Si is present to combine with all the Mg, Fe, Mn as $Mg_2Si$ and Al(Fe,Mn)Si.

| Nominal Composition | | | |
|---|---|---|---|
| Alloy | Si | Mg | Fe |
| Invention | 0.70 | 0.35 | 0.2 |
| AA6106 | 0.6 | 0.5 | 0.2 |
| AA6063A | 0.5 | 0.63 | 0.2 |

**[0006]** The alloys have a number of advantages. It should be understood that not all the stated advantages are necessarily achieved by all the alloys. Also, a particular property may not be an improvement on some other alloy. But most of the advantages are possessed by most alloys according to the invention, and it is this combination that represents a significant advance in the art:

- Extrusion ingots of the alloys are capable of being extruded at relatively high speeds, typically around 75% of the maximum extrusion speed of AA6063 alloys.
- The extrusion pressures required are lower than for AA6063 alloys, which reduces equipment and operating costs.
- The extrusions are air quenchable.
- The extrusions have a surface quality which is acceptable for most architectural applications.
- By particular means, e.g. the addition of Mn as discussed below, the surface quality of the extrusions can be made to be better than for any related alloy compositions.
- The extrusions are capable of being aged to a tensile strength in excess of 240 MPa, often in excess of 250 MPa, with acceptable toughness.
- A two-stage or ramped ageing process is particularly effective in improving aged properties.

**[0007]** The Mg content of the invention alloy is set at 0.25 - 0.40%. If the Mg content is too low, it is difficult to achieve the required strength in the aged extrusions. Extrusion pressure increases with Mg content, and becomes unacceptable at high Mg contents.

**[0008]** The Si content is set at 0.6 - 0.9%. If the Si content is too low, the alloy strength is adversely affected, while if the Si content is too high, extrudability may be reduced. The function of the Si is to strengthen the alloy without adversely affecting extrudability, high temperature flow stress, or anodising and corrosion characteristics.

**[0009]** Fe is not a desired component of the alloy, but its presence is normally unavoidable. An upper concentration limit is set at 0.35%, and a preferred range at 0.15 - 0.35% (because alloys containing less Fe are more expensive). In the as-cast alloy ingot, Fe is present in the form of large plate-like β-AlFeSi particles. Preferably the extrusion ingot is homogenised to convert β-AlFeSi to the α-AlFeSi form. It is known however that excess Si (over the amount required to form $Mg_2Si$) stabilises the β-AlFeSi phase, which has a detrimental effect on extrudability and in particular on extrusion surface quality. Where extrusion surface quality is important, this problem may be avoided by homogenising the extrusion ingot under special conditions or by modifying the alloy composition.

**[0010]** Mn is included in the alloys in order to improve extrusion surface quality. Mn acts to accelerate the β to α-AlFeSi transformation during homogenisation, so that the resulting homogenised ingot has improved extrudability, that is to say improved extrusion surface quality. Above 0.35% Mn, further improvements are not seen, or are not commensurate with the added cost, and the extrudates may show increased quench sensitivity. A preferred Mn content is 0.10 - 0.25%.

**[0011]** In the age-hardened extrusions, it is apparent that some of the Si is present as $Mg_2Si$ and some more is present as AlFeSi. In preferred compositions according to the invention, the excess Si, over the amount required to combine with all the Mg and Fe present, is at least 0.3%.

**[0012]** An extrusion ingot of the alloy may be made by any convenient casting technique, e.g. by a DC casting process preferably by means of a short mould or hot-top DC process. The Fe is preferably present as an insoluble secondary phase in the form of fine β-AlFeSi platelets preferably not more than 15 μm in length or, if in the α form, free from script and coarse eutectic particles.

**[0013]** The as-cast extrusion ingot is homogenised, partly to bring the soluble secondary magnesium-silicon phases into suitable form, and partly to convert β-AlFeSi particles into α-AlFeSi particles, preferably below 15 μm long and with 90% below 6 μm long. Homogenisation typically involves heating the ingot at 550 - 600°C for 30 minutes to 24 hours, with higher temperatures requiring shorter hold times. As noted above, optimum homogenisation conditions may depend on the presence and concentration of added Mn.

**[0014]** The homogenised extrusion ingot is hot extruded, under conditions which may be conventional. The emerging extrusion is quenched, either by water or forced air or more preferably in still air, and subjected to an ageing process in order to develop desired strength and toughness properties.

**[0015]** Ageing typically involves heating the extrusion to an elevated temperature in the range 150 - 200°C, and holding at that temperature for 1 - 48 hours, with higher temperatures requiring shorter hold times. A surprising feature of this invention is that the response of the extrusion to this ageing process depends significantly on the rate of heating. A rate of heating is from 10 - 100°C, particularly 10 - 70°C, per hour; if the heating rate is too slow, low throughput results in increased costs; if the heating rate is too high, the mechanical properties developed are less than optimum. An effect equivalent to slow heating can be achieved by a two-stage heating schedule, with a hold temperature typically in the range of 80 - 140°C, for a time sufficient to give an overall heating rate within the above range.

**[0016]** When aged to peak strength, extrusions are typically found to have an ultimate tensile strength of at least 240 MPa, often greater than 250 MPa, with acceptable toughness.

**[0017]** Reference is directed to the accompanying drawings in which:-

Figure 1 (already referred to) is a compositional plot showing the Aluminum Association specification ranges for Mg and Si for various alloys alongside the alloys of the present invention (the blank rectangle containing the filled circle).

Figure 2 is a bar diagram showing the effect of alloy composition and homogenisation temperature on the maximum extrusion pressure of 250 MPa target alloys extruded into a 5 x 20 mm section.

Figure 3 is a bar diagram showing the effect of alloy composition and homogenisation temperature on the surface roughness measurement of 250 MPa target alloys extruded into a 5 x 20 mm section.

Figure 4 is a bar diagram showing the effect of alloy composition and homogenisation temperature on 20° gloss (reflectivity) measurement of 250 MPa target alloys extruded into 5 x 20 mm section.

Figure 5 is a bar diagram showing the effect of alloy composition on the mechanical properties of 250 MPa target alloys, which had been homogenised for 2 hours at 580°C, extruded into a 5 x 20 mm section, forced air quenched, and aged for 7 hours at 175°C. The properties were measured at the back of the extrusion.

Figure 6 is a graph showing the effect of ramp rate to the ageing temperature (5 hours at 185°C) on the tensile strength of two dilute 6000 series alloys, including a very high excess Si alloy containing no Mn and otherwise having a composition within the scope of the present invention.

Figure 7 is a bar diagram showing surface roughness of the alloys extruded in Example 4.
Figure 8 is a bar diagram showing tensile properties of the alloys extruded in Example 4.

## EXAMPLE 1

**[0018]** Extrusion trials were carried out using an experimental extrusion press, in which the alloys given in Table 1 below were extruded. These alloys represent a low Mg-containing alloy, with and without an addition of 0.12% Mn, together with typical AA6063 and AA6106 compositions, again with and without an addition of about 0.12% Mn. The nominal alloy composition of the invention is shown as a filled circle in the compositional plot of Figure 1.

**[0019]** Extrusion ingots were DC cast and were homogenised for 2 hours at 570°C or 580°C. They were then hot extruded.

**[0020]** Extrusion pressure was recorded, and maximum extrusion pressure data for the alloys are given in Figure 2. Thus, this data shows that the extrusion pressure of the alloy type significantly lower than that of the AA6106 and AA6063A alloys. The addition of Mn to the base composition may reduce the extrusion pressure still further, but is found to be dependent upon the precise homogenisation conditions used (see Figure 2).

**[0021]** The surface quality of the extrudate was assessed using both profilometry and Gloss (reflectivity) measurements, and the data obtained using these techniques are given in Figures 3 and 4. From Figure 3, it can be seen that the lowest value of mean surface roughness (Ra), for a given homogenisation condition, is produced in extrudate from the optimum alloy composition (the low Mg, Mn-containing alloy). The same alloy also gives the highest Gloss measurement, again for a given homogenisation treatment. Therefore, the alloy has been shown to have the best surface quality of the alloys evaluated.

**[0022]** The tensile properties and Kahn tear toughness of the extrudate from each alloy was evaluated following "peak" ageing (7 hours at 175°C), and the relevant data are shown in Figure 5. It can be seen from this figure that the tensile properties and the toughness of the alloy of the invention are equivalent to those of the AA6106 and AA6063A alloys.

## EXAMPLE 2

**[0023]** An allloy of composition: 0.65Si-0.33Mg-0.19Fe-0.08Mn was evaluated in extrusion trials. This alloy showed reduced extrudability as compared with "conventional" AA6060 alloys, but the maximum attainable extrusion speed was still relatively high (up to =80 m/min) in comparison with AA6063 alloys. The application of two stage ageing practice to extrudate of this alloy showed that the tensile properties could be improved significantly as compared with material aged "conventionally" (see Table 2).

## EXAMPLE 3

**[0024]** The application of a ramped ageing practice to extrusions made of two dilute 6000 series alloys is shown in Figure 6, in which the response of the extrusions to slow ramp rates is demonstrated. The composition of the alloys were:-

Excess Si AA6060 alloy: 0.35 Mg - 0.52 Si - 0.20 Fe.
Very high excess Si alloy: 0.35 Mg - 0.70 Si - 0.20 Fe.

## EXAMPLE 4

**[0025]** Extrusion trials were carried out using 180 mm diameter billets. The compositions of the trial alloys are given in Table 3.

**[0026]** Surface quality of the extrusions is shown in Figure 7. The experimental alloy gives a "less rough" surface than either of the other two alloys.

**[0027]** Tensile properties of the extrusions, after ageing to peak strength, are set out in Figure 8. The expermented alloy has properties equivalent to the AA6063A alloy, and their tensile strength well in excess of 250 MPa with acceptable toughness.

| Alloy | Si | Mg | Fe | Mn | |
|---|---|---|---|---|---|
| 1 | 0.74 | 0.34 | 0.20 | — | High excess Si |
| 2 | 0.73 | 0.33 | 0.20 | 0.12 | |
| 3 | 0.58 | 0.49 | 0.20 | — | Excess Si AA6106 |
| 4 | 0.60 | 0.49 | 0.19 | 0.12 | |
| 5 | 0.49 | 0.63 | 0.18 | — | Balanced AA6063A |
| 6 | 0.51 | 0.64 | 0.19 | 0.11 | |

**Table 1 - Analysed compositions of the alloys cast in the development programme for an alloy capable of achieving a tensile strength of ~250MPa.**

| Ageing Practice | 0.2% PS (MPa) | UTS (MPa) | elongation (%) | Toughness (kJ/m²) |
|---|---|---|---|---|
| 185°C (8 hr cycle) | 216 | 245 | 10.7 | — |
| 3 hrs at 120°C + 5 hrs at 185°C | 229 | 259 | 10.4 | 114 |

**Table 2 - Tensile properties and Kahn tear toughness of a high excess Si alloy (0.65Mg-0.33Mg-0.19Fe-0.08Mn, following "conventional" and ramped ageing.**

**COMMERCIAL TRIAL: ALLOY COMPOSITIONS**

| Alloy | Mg | Si | Fe | Cu | Mn | Cr |
|---|---|---|---|---|---|---|
| AA6063 | 0.51 | 0.43 | 0.17 | 0.012 | 0.024 | 0.001 |
| AA6063A | 0.62 | 0.51 | 0.16 | 0.010 | 0.032 | 0.001 |
| Experimental Alloy | 0.36 | 0.69 | 0.19 | 0.004 | 0.12 | 0.001 |

Table 3

## Claims

**1.** An extruded section of the following composition in weight %, in which Fe is present as α-AlFeSi:

| | |
|---|---|
| Mg | 0.25 - 0.40 |
| Si | 0.60 - 0.90 |
| Mn | up to 0.35 |

(continued)

| | |
|---|---|
| Fe | up to 0.35 |
| Others | up to 0.05 each, 0.15 total |
| Al | balance. |

wherein the extruded section has after ageing an ultimate tensile strength of at least 240MPa.

**2.** An extruded section as claimed in claim 1, comprising:

| | |
|---|---|
| Fe | 0.15 - 0.35 |
| Mn | 0.10 - 0.25 |

**3.** An extruded section made by extruding an extrusion alloy of composition in weight %

| | |
|---|---|
| Mg | 0.25 - 0.40 |
| Si | 0.60 - 0.90 |
| Mn | 0.10 - 0.35 |
| Fe | up to 0.35 |
| Others | up to 0.05 each, 0.15 total |
| Balance | Al, |

wherein the extruded section has after ageing an ultimate tensile strength of at least 240MPa.

**Patentansprüche**

**1.** Extrudiertes Teilstück der folgenden Zusammensetzung in Gew.%, in dem Fe als α-AlFeSi vorliegt:

| | |
|---|---|
| Mg | 0,25 bis 0,40 |
| Si | 0,60 bis 0,90 |
| Mn | 0,10 bis 0,35 |
| Fe | bis zu 0,35 |
| Andere | bis zu jeweils 0,05, insgesamt 0,15 |
| Al | Rest |

wobei das extrudierte Teilstück nach dem Härten eine Reissfestigkeit von mindestens 240 MPa aufweist.

**2.** Extrudiertes Teilstück gemäss Anspruch 1, umfassend:

| | |
|---|---|
| Fe | 0,15 bis 0,35 |
| Mn | 0,10 bis 0,25 |

**3.** Extrudiertes Teilstück, das durch Extrudieren einer Extrusionslegierung der Zusammensetzung, in Gew.%,

| | |
|---|---|
| Mg | 0,25 bis 0,40 |
| Si. | 0,60 bis 0,90 |
| Mn | 0,10 bis 0,35 |
| Fe | bis zu 0,35 |
| Andere | bis zu jeweils 0,05, insgesamt 0,15 |
| Al | Rest |

hergestellt wird, wobei das extrudierte Teilstück nach dem Härten eine Reissfestigkeit von mindestens 240 MPa aufweist.

## Revendications

**1.** Tronçon extrudé de la composition suivante en % en poids, dans lequel Fe est présent sous la forme α-AlFeSi :

| | |
|---|---|
| Mg | 0,25 - 0,40 |
| Si | 0,60 - 0,90 |
| Mn | 0,10 - 0,35 |
| Fe | jusqu'à 0,35 |
| Autres | jusqu'à 0,05 chacun, 0,15 au total |
| Al | solde, |

le tronçon extrudé ayant après vieillissement une résistance à la traction finale d'au moins 240 MPa.

**2.** Tronçon extrudé selon la revendication 1, comprenant

| | |
|---|---|
| Fe | 0,15 - 0,35 |
| Mn | 0,10 - 0,25. |

**3.** Tronçon extrudé fabriqué en extrudant un alliage d'extrusion de composition en % en poids

| | |
|---|---|
| Mg | 0,25 - 0,40 |
| Si | 0,60 - 0,90 |
| Mn | 0,10 - 0,35 |
| Fe | jusqu'à 0,35 |
| Autres | jusqu'à 0,05 chacun, 0,15 au total |
| Solde | Al, |

le tronçon extrudé ayant après vieillissement une résistance à la traction finale d'au moins 240 MPa.

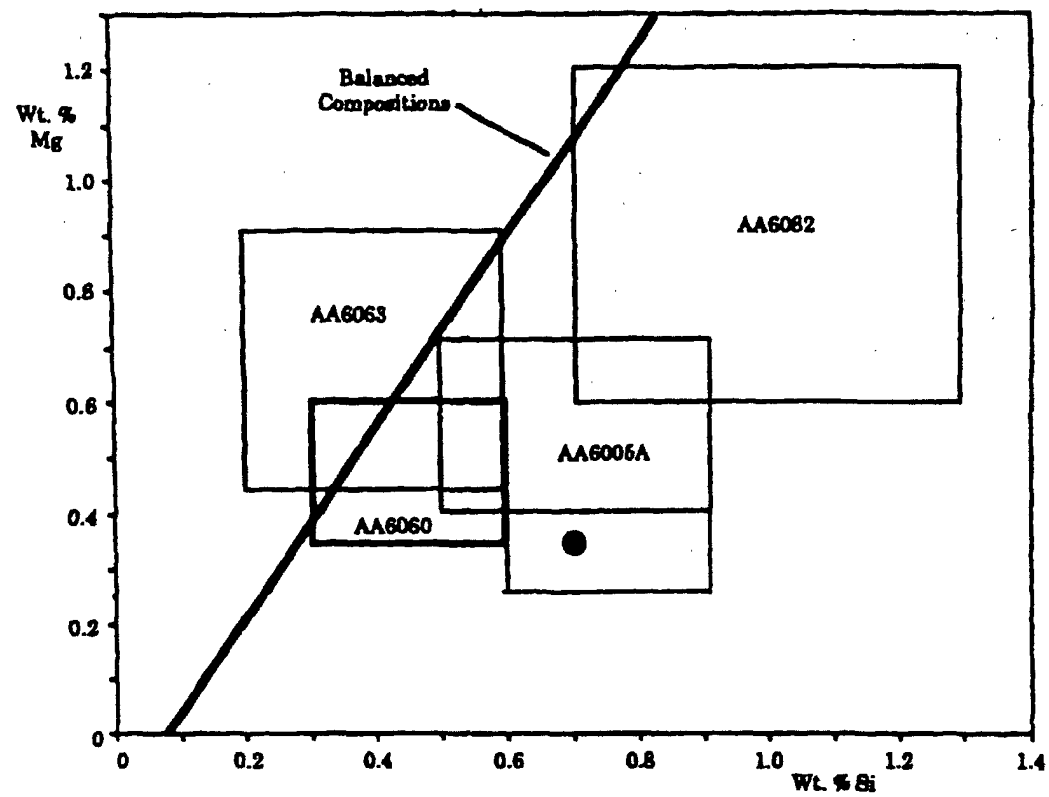



Figure 1

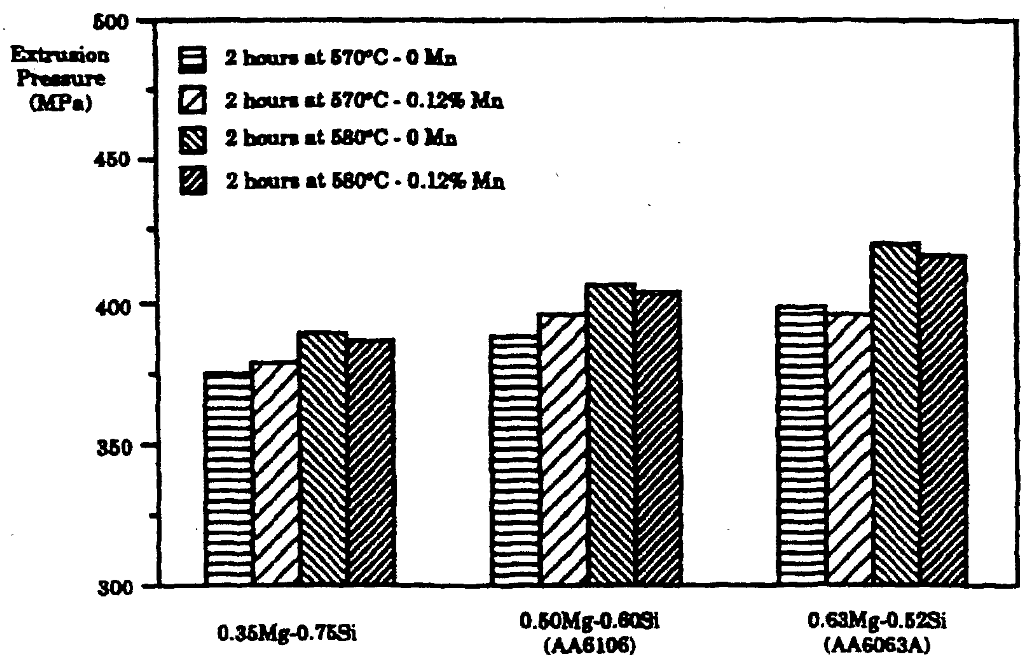



Figure 2

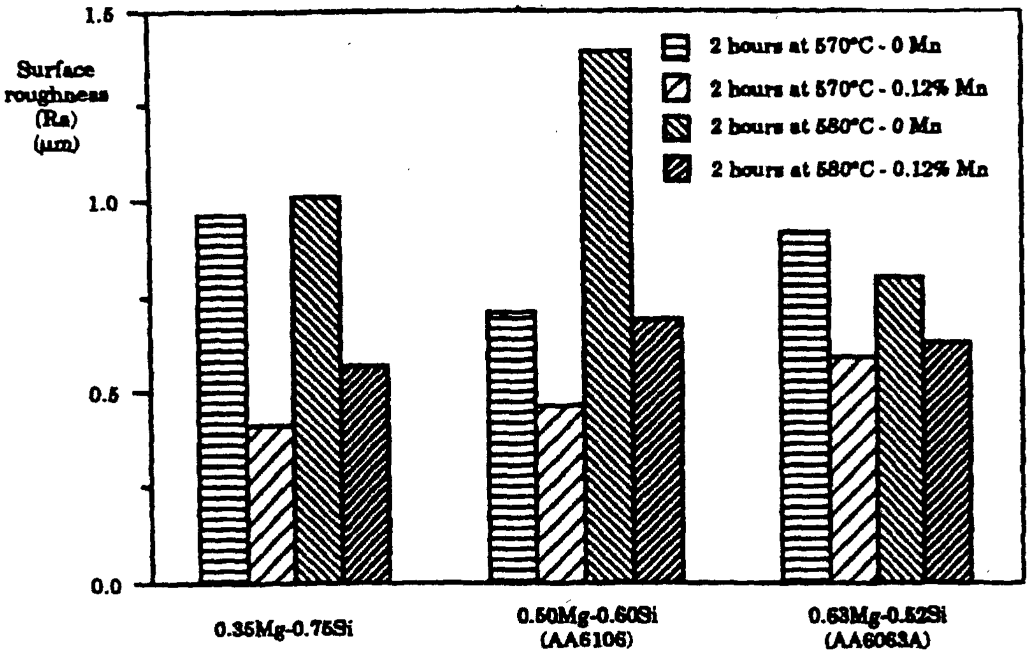



Figure 3

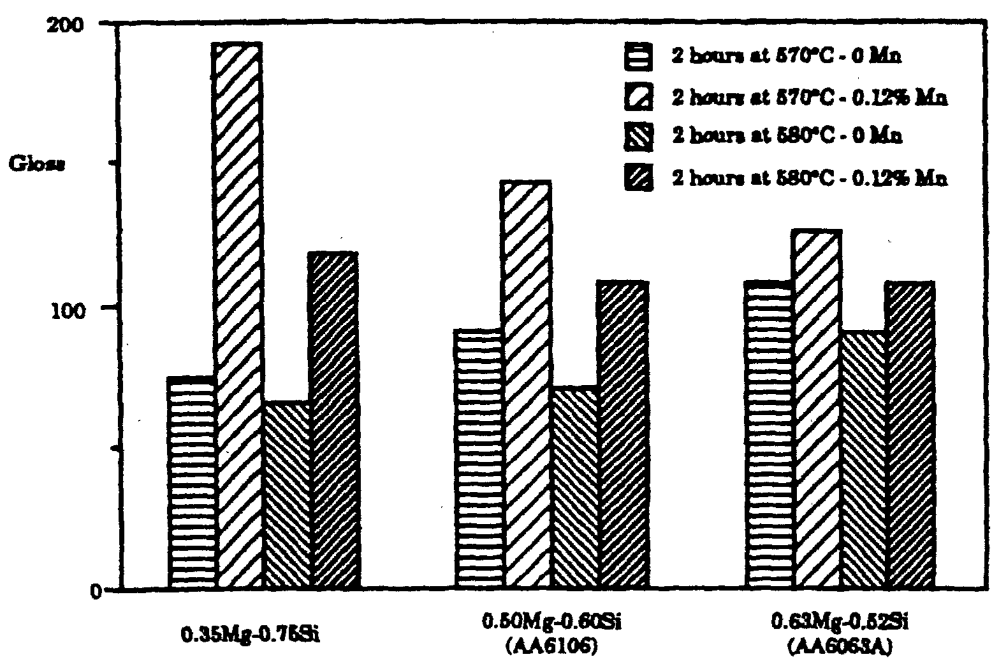



Figure 4

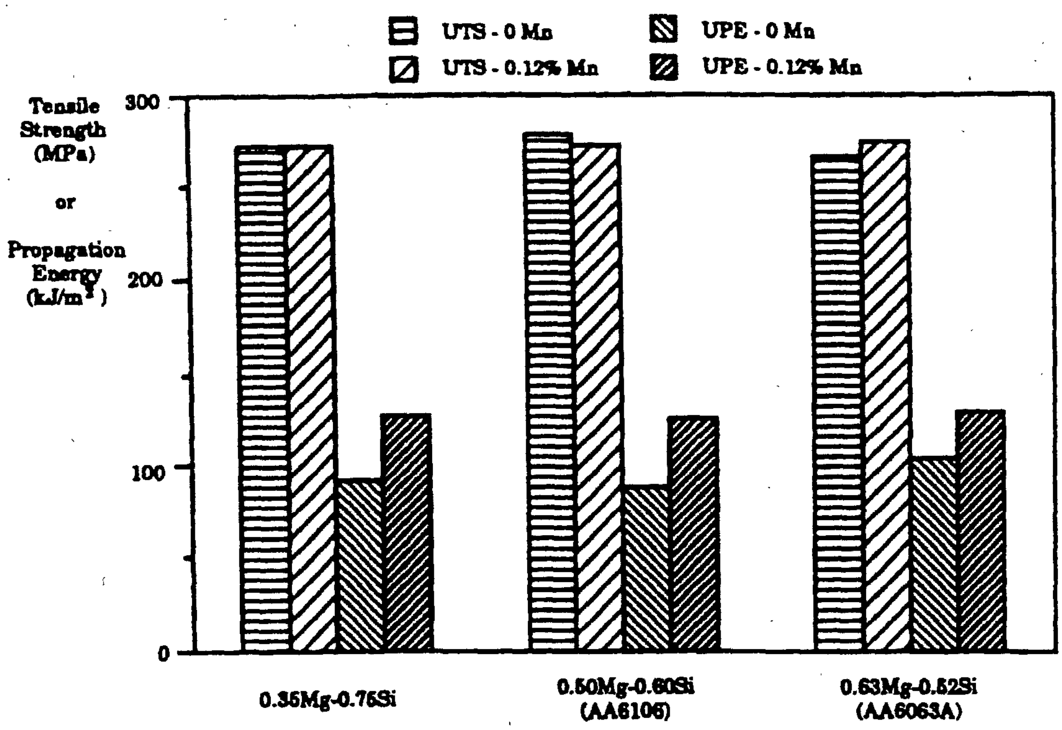



Figure 5

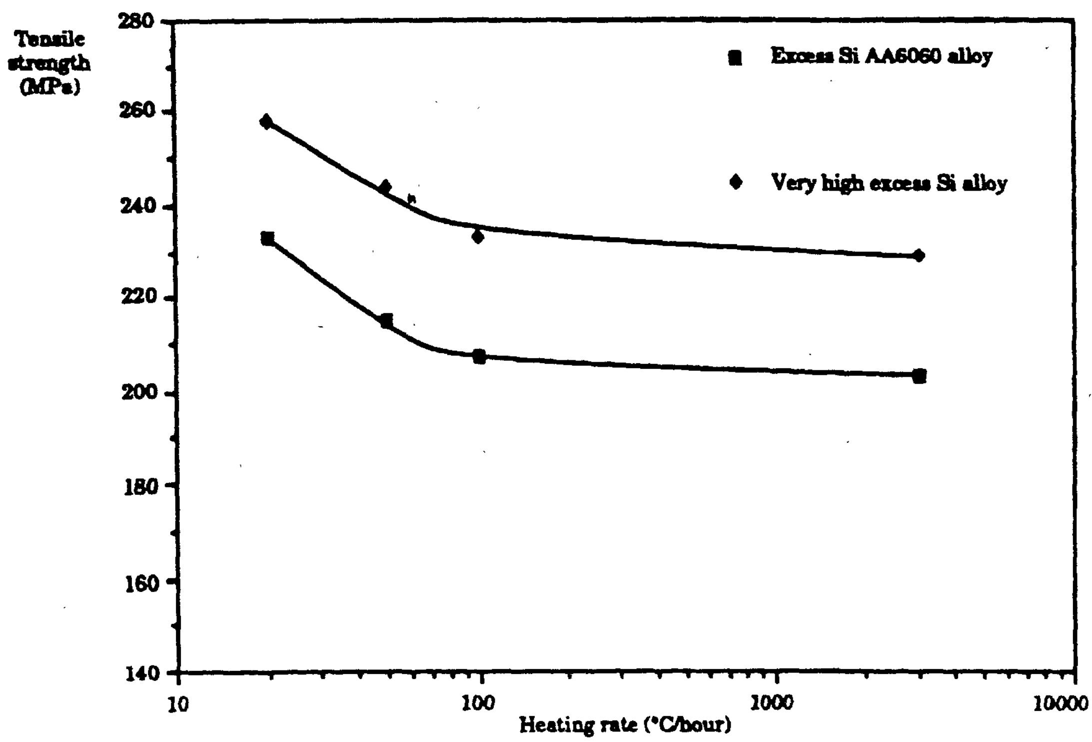
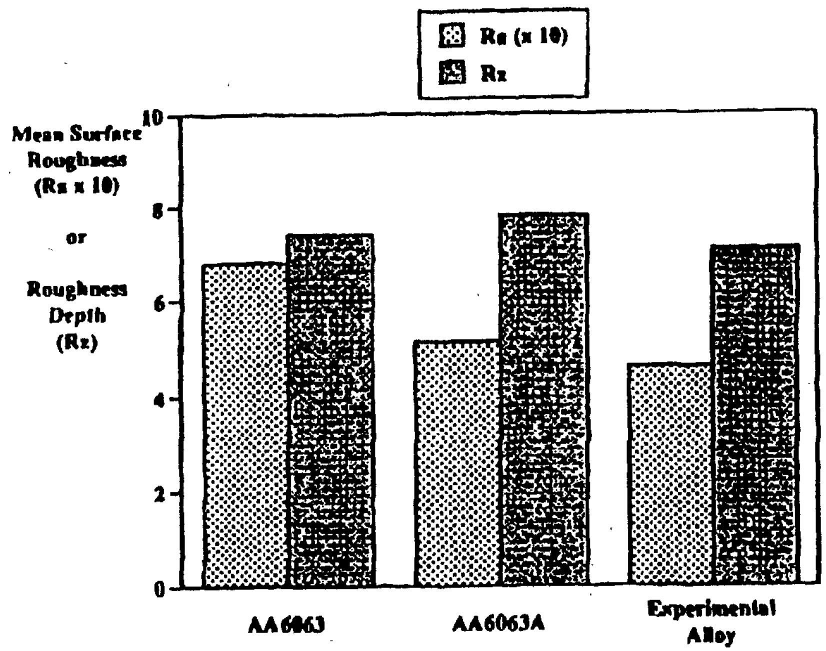


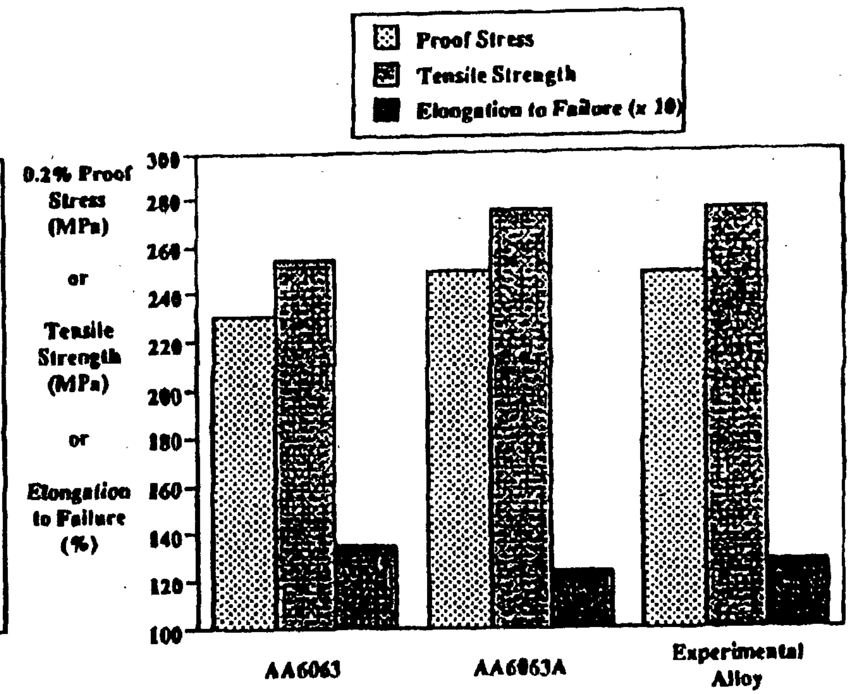

Figure 6

# EXPERIMENTAL ALLOY PROPERTIES




SURFACE ROUGHNESS

Figure 7




TENSILE PROPERTIES

Figure 8