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EUTECTIC MICROSTRUCTURES OF Al-ThAl3 and Al-UAl4 ALLOYS

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1 Introduction

The morphology of eutectic alloys in binary systems is dependent on several parameters(1). Some of them are related to the systems such as the growth mechanism of the eutectic phases(2), volume fraction of the phases(3), interface energy between the two solid phases(4), thermal conductivity of the solid phases(5), alloy composition including impurities and deviations from the eutectic compositions and the external variables such as growth rate and thermal gradient in the liquid(6).

In metal systems when both eutectic phases have non faceted growth mechanism, there is a tendency to a regular microstructure and are known as normal eutectics(7). When one phase has non faceted growth and the other faceted growth, the eutectic used to present irregular and complex regular microstructures are usually referred to as anomalous eutectics.

The volume ratio of the phases is a parameter which depends among other variables on the growth mechanism of the phases. Low volume fraction of one phase in normal eutectics shows the tendency for fibers and greater volume fraction increases the probability for lamellar microstructures. Anomalous eutectics also present fibrous structures for low volume fraction of the faceted phase and complex regular or quasi regular microstructures for greater volume fractions(3). However, if the surface of contact between the solid phases is a single, low energy crystallographic plane there is a strong probability for lamellar microstructures and if it has more than one low energy surface the probability for fibrous microstructures increases. The fibers usually form boundaries with a variety of planes.

Impurities can change the growth mechanism of the phases and the surface energy between the solid phases. The modification of commercial Al-Si alloys by Na and the addition of Mg to obtain nodular cast iron are examples of technological importance. Eutectic celular growth also can be promoted by impurities(8).

One or more of these parameters can influence the morphology of the binary eutectic but it has seen that even this morphology can be changed by variables such as thermal gradient in the liquid (G) and growth rate (R). The morphologies of normal and anomalous

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eutectics can be modified by altering G and\or R but its effects are more pronounced on anomalous eutectics.

Another interesting fact in eutectic systems is the possibility to obtain eutectic microstructures with non eutectic compositions. The coupled eutectic growth is kinetically controled and the range of compositions and temperatures where it happens can be drawn in the phase diagram as coupled zone.The extension of the coupled zone depends also on the variables G and R (9).

This paper deals on the microstructures of systems Al-ThAl3 and Al-UAl4, which are composed by a non faceted phase θ(aluminium) and an intermetallic phase (ThAl3 or UAl4) which is normally faceted phase.The volume fraction of UAl4 and ThAl3 are 10,0% and 14,3% respectively.The eutectic compositions are 13 wt% and 20.4 wt% of UAl4 and ThAl3 respectively.(10).

2 Experimental Procedure

The Al-U alloys were prepared by dissolution of metallic uranium in liquid aluminium.The Al-Th alloys were prepared by ThO2 reduction by liquid aluminium.The experimental work was started with 99,5 wt% purity materials.A great number of compositions around the eutectic point were prepared in an induction furnace.Each alloy was poured as small ingots 120 mm long and 8 mm in diameter.

These ingots were unidirectionally solidified in an apparatus shown in Fig.1.In this equipment the sample in the alumina tube is held in position and the furnace moved at the required speed.The thermal gradient (G) was constant and the speed of the furnace varied from 4 to 400 mm/h.

The microstructures were observed by optical and scanning electron microscopy.

Chemical and eletrolytic etching was used for optical microscopy,as following:
Chemical etching: aqueous solution 1 vl% HF
Eletrolytic polishing and etthing:volumetric composition
perclorlc acid-20%
ethyl alcohol-70%
ethylen glycol-10%

Scanning electron micruscopy(SEM) was performed after seletive etching of the aluminium matrix with an aqueos 5% NaOH solution at 60 C.

3 Conventional Ingots Microstructures

Typical microstructure of hypoeutectic aluminium uranium alloys is presented in Fig. 2 (less than 13 wt% U).It shows primary dendritic θ(aluminium solid solution) and interdendritic eutectic(θ+UAl4).

Eutectic and hypereutectic alloys presented a similar microstructure (Fig. 2),with less α dendritic phase.A fully eutectic microstructure was not obtained in the compositions that we tried out.

Greater uranium content in the hypereutectic alloys presented primary UAl_4,as shown in Figs 3a and 3b.It can be seen in Fig. 3a that UAl_4 is enclosed by α dendrites and eutectic(α+UAl_4).Fig. 3b shows that the primary UAl_4 phase has a hollow prismatic lozenge shape as hopper crystals(11).

The lamellar microconstituent usually is oriented in two main directions.Sometimes the eutectic showed well developed spiral formation with a lozenge shaped UAl_4(Fig.4) but this was the exception,not the rule.

Hypoeutectic microstructure of the aluminium thorium alloys is shown in Fig. 5 (less than 20.4 wt% Th).Primary dendritic α(aluminium solid solution) and interdendritic eutectic(α+$ThAl_3$) can be seen in the photomicrography

The eutectic and hypereutectic compositions of the Al-Th alloys also present the same microstructure as in Fig. 5.In this micrograph the eutectic shows lamellar morphology with more than one direction for the $ThAl_3$ in some positions.

Only one of the hypereutectic compositions has presented fully eutectic microstructure (Fig. 6).In the external part of the ingot(greater cooling rate) a fine undefined microstructure can be seen.The central zone is formed by a coarser microstructure of non regular $ThAl_3$ in a α matrix.The fine external microstructure at a higher magnification is presented in Figs. 7a and 7b with well developed hexagonal spiral eutectic

Higher thorium concentrations shows microstructures with primary $ThAl_3$,as shown in Figs. 8a and 8b.The primary $ThAl_3$ is surrounded by α dendritic and eutectic.The observation of selectively etched sample shows that most of the primary $ThAl_3$ has a hollow prismatic hexagonal shape.

The spiral arrangement of the eutectic was not often found but it was present in both systems (Al-U and Al-Th).The spiral morphology was similar to the intermetalic morphology.Such results indicate that the faceted growth mechanism of the intermetalic phase has a strong influence on the eutectic morphology.

Both systems ,also present the same features in relation to the solidification sequence of the phases and final microstructures.The coupled zone presented in Fig. 9 can be used to explain the results.This figure represents schematically the coupled zone for the system Al-UAl_4 and Al-$ThAl_3$ and the associated solidification sequences for eutectic (Fig.9a) and hypereutectic (Fig.9b) compositions.Using this figure it can be seen that for an eutectic composition the primary α phase starts the crystallization at an undercooling indicated by the point A and the eutectic by the point B.Hyp ereutectic alloys which have primary intermetallic phase,it starts the crystallization at the indicated point A,the liquid decreases the aluminium content and the θ dendritic phase develops at point B and the eutectic at point C.All the microstructures in the two systems can also be qualitatively explained by this coupled zone concept.

4 Unidirectional Solidification Microstructures

Hypoeutectic,eutectic and some hypereutectic compositions in the two systems present both θ dentritic phase and eutectic.Fig. 10 and Figs. 11a and 11b show examples of these microstructures for Al-U and Al-Th alloys

Microstructures which have a primary intermetallic phase are shown in Figs. 12a and 12b and Figs. 13a and 13b for Al-U and Al-Th alloys.Both show detailed primary morphology and its hollow growth.

Fully eutectic microstructures were produced only with hypereutectic compositions. Such results can also be explained by the coupled zone, taking in account that the existence of a definite gradient in the liquid G changes the extension of the coupled zone.

Eutectic microstructures formed at different growth rates are described in the following figures.In the eutectic Al-UAl4 solidified at the lowest rate the second phase is present in both forms,rods and broken lamellas (Figs. 14a and 14b).Cellular microstructures can be seen on Figs. 15a and 15b which are typical for intermediate solidification rates.It can be seen two main directions of the UAl4 in the cells centers and a degenerate microstructure at the cells boundaries.In reality,the broken lamellar shape of UAl4 is connected in space,as can be seen in Fig. 16.The morphology of eutectic at the highest growth rate is shown in Fig. 17,indicating the tendency for spiral growth.

These eutectic morphologies confirm the great influence of the faceted phase and indicates that the small volume fraction creates difficulties in developing the spiral.The influence of growth rate is also demonstrated.The faceting of the UAl4 phase seems to dominates at greater growth rates and decreases its effect at lower growth rates when the low volume fraction is responsible for the broken lamellar or rod morphologies.

These microstructures also show qualitatively a decrease of intereutectic phase distance with the increase in the growth rate.

The eutectic morphology of the Al-ThAl3 showed quasi regular faceted rods of ThAl3 in θ matrix,the rods tending to the some morphology of the proeutectic ThAl3.This morphology was obtained at all speeds of the equipment,with a decrease in the mean distance of the rods at greater speeds.Figs 18a, 18b,19 and 20 show the eutectic microstructures.

The spiral morphology could probably be obtained at speeds higher than that of our equipment(400 mm/h),if the conventional ingot results are considered.

Also in this system(Al-ThAl3) the morphology must be influenced by the growth anisotropy of the phases,the volume fraction and the impurities in the alloying.Other faceted non faceted systems showed changes from a quasi regular to complex regular morphology as the growth rate increases(5,12).

5 Comments and Conclusions

The microstructures presented in the Al-UAl4 and Al-ThAl3 systems in the conventional and unidirectionally solidified ingots can be explained by the coupled zone concept.An assymetrical coupled zone as showed in fig. 9 is usual for faceted non faceted eutectics and very different slopes of the liquidus lines(9).The microstructures also qualitatively confirm this shape for the coupled zone in both systems.

Both systems showed spiral eutectics with the same morphology of the faceted primary phase.This indicates that the faceted phase is the leading phase in the eutectic growth and a decisive factor of the complex regular morphology.The advance of the leading phase must decrease at lower growth rates (increasing G/R) and decrease its influence on the morphology.In the latter situation the eutectic Al-UAl4 becomes broken lamellar or fibrous and the Al-ThAl3 quasi regular fibrous.

Another common feature of these eutectics was the decrease of the mean interphase distance in the eutectic with growth rate increase.

The experimental results permit the followings conclusions:

1 The eutectic morphology of Al-UAl4 and AlThAl3 show a tendency for spiral growth at high growth rates.

2 The complex regular spiral eutectics in these systems show the same morphology of the primary intermetalic phase.

3 The unidirectional morphology of the Al-UAl4 eutectic showed tendency for spiral growth at higher speeds and changed to broken lamellar and fibrous at lower speeds.

4 The unidirectional morphology of Al-ThAl3 showed always quasi regular rods of ThAl3 in an aluminium matrix.

5 The coupled zone can be used to explain the microstructures obtained in conventional and unidirectional ingots.

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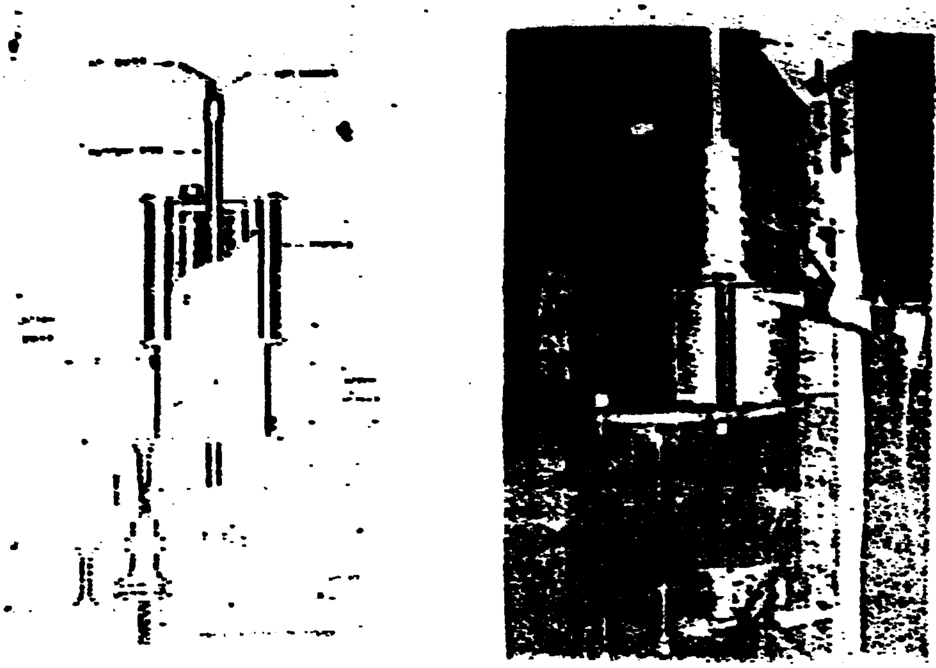
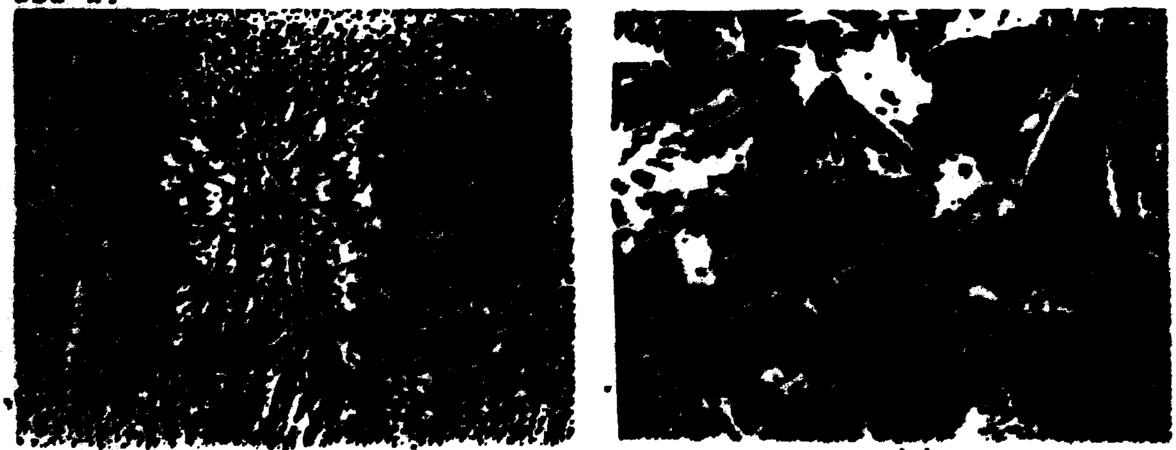


(a) (b)

Figs.1 Apparatus for unidirectional solidification .a)Drawing.b)Photography

Fig.2 Al 11wt%U Hypoeutectic alloy.Electrolitic polishing. 800 x.



(a) (b)

Figs.3 a)Al 19wt%U Hypereutectic alloy.Etch:HF.200 x.b) Al 20wt%U Hypereutectic alloy.UAl4 proeutectic.SEM.600 x.

Fig.4 Al [illegible] eutectic.
Al 19wt%[illegible], Etch-HF, 750 x.

Fig.5 Al 17wt%Th Hypoeutectic alloy, Etch-HF, [illegible]

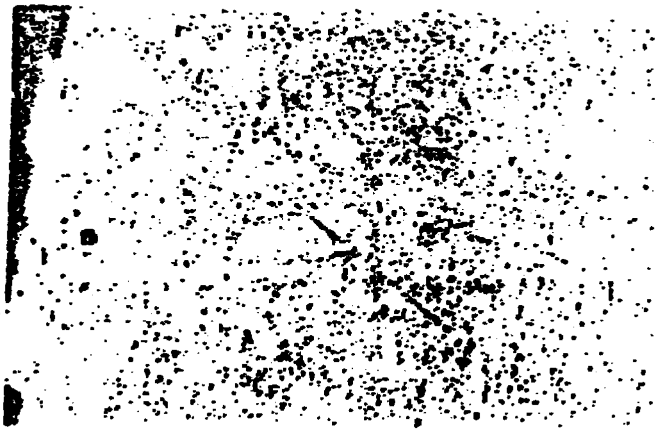
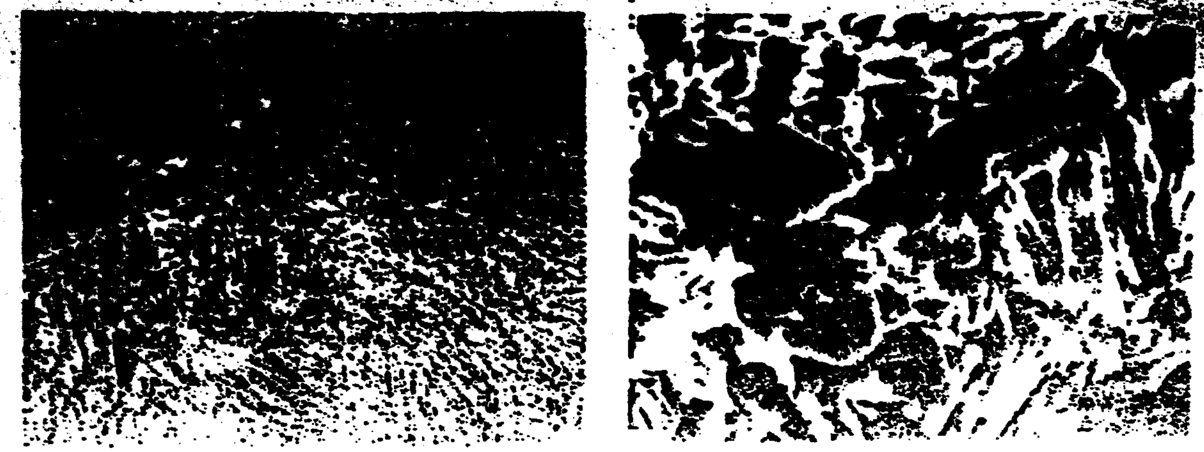


Fig.6 Al 20.9wt%Th, Etch-HF, 100 x.

(a) (b)

Figs.7 a) The complex regular morphology of Fig. 6, 750 x.
b) ThAl3 in the complex regular spiral morphology, SEM, [illegible]



Figs.8 a)Al-[illegible] Hypereutectic alloy. Etch-HF, 100 x. b) ThAl3 proeutectic in the same alloy. SEM 200 x.

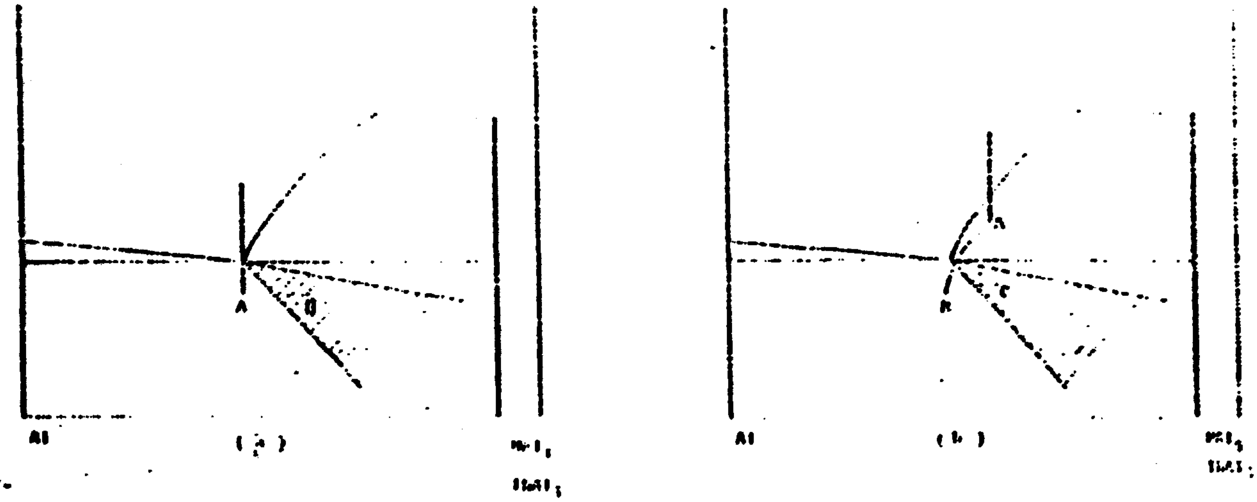
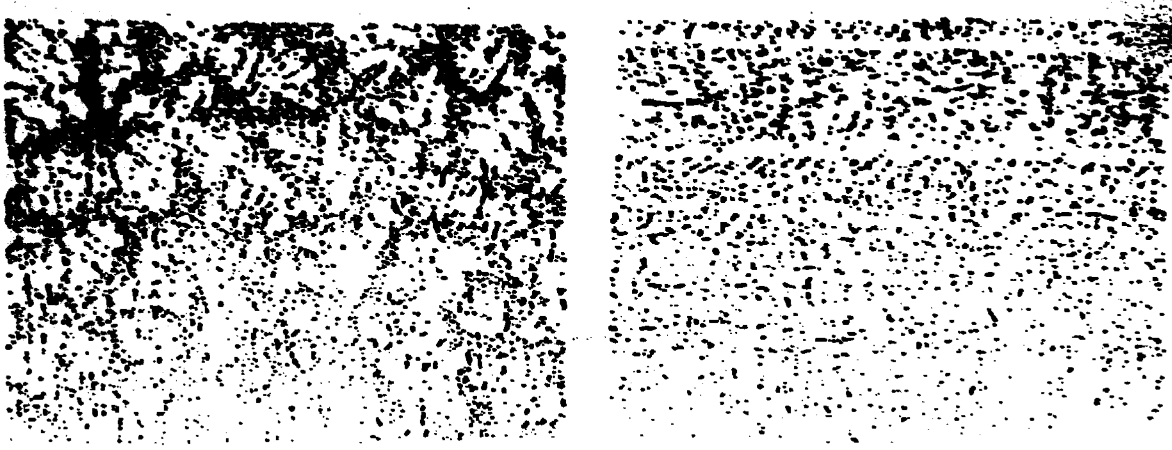


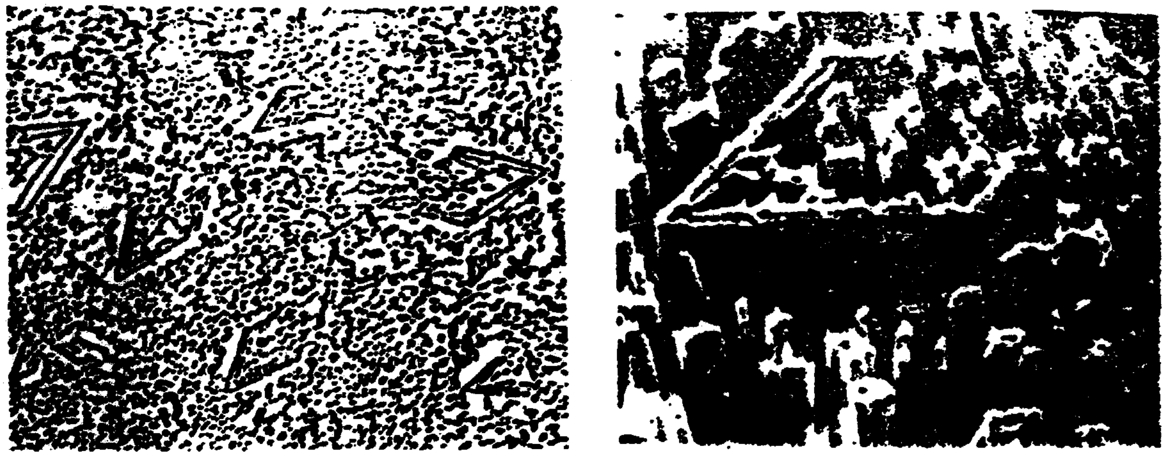
Fig.9 Coupled Zone in the Systems Al-ThAl3 and Al-UAl4. a)Eutectic composition. b)Hypereutectic alloy and formation of proeutectic UAl4 or ThAl3.

Fig.10 Al 11wt%U Hypoeutectic alloy. Transverse section. R 40 mm/h. Etch-HF, 175 x



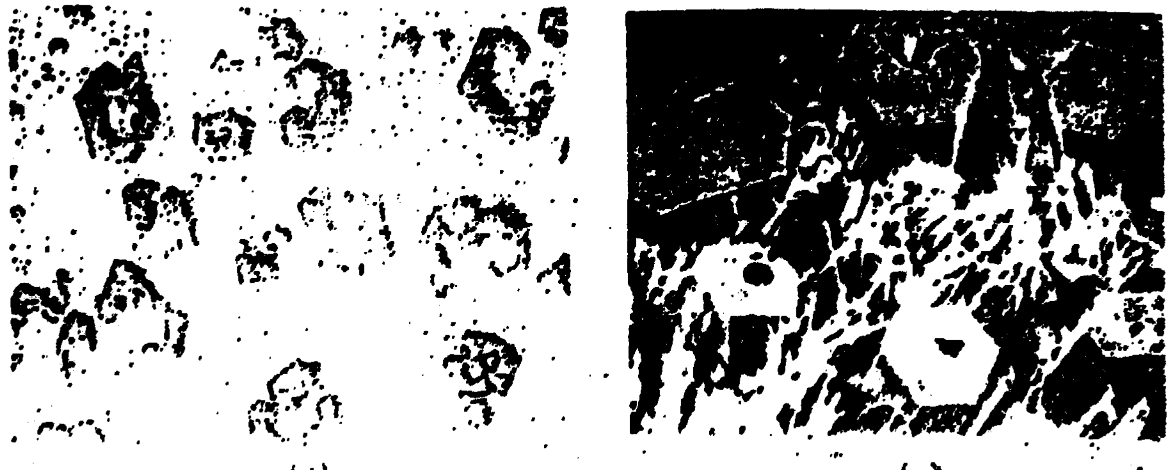
(a) (b)

Figs.11 Al [illegible] alloy.R [illegible] mm/h.Etch HF.a)Transverse section.150 x.b)Longitudinal section.75 x.



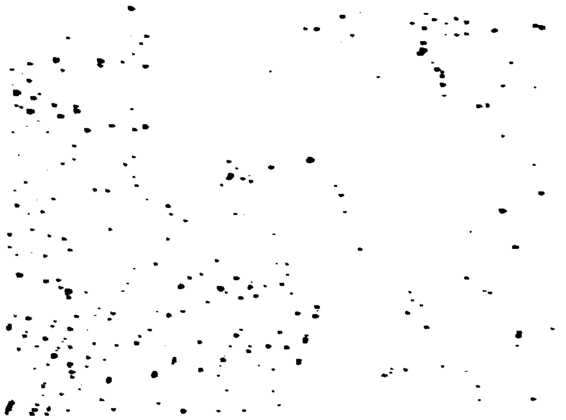
(a) (b)

Figs.12 Al 16w[illegible] alloy.R-40 mm/h.a)Transverse section.Etch HF.150 x.b)Selective Etch.SEM.500 x.



(a) (b)

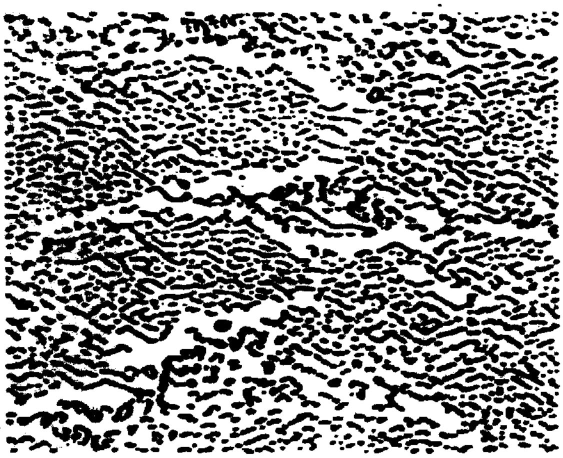
Figs.13 Al 30wt[illegible] alloy.R [illegible] mm/h.a)Transverse section.Etch HF.[illegible] x.b)Selective Etch.SEM.150 x.



(a)

(b)

Figs.14 Al 11,[illegible]wt%U alloy. R [illegible] mm/h. a)Transverse section Etch-HF, 500 x. b)Selective Etch, SEM, 650 x.



(a)

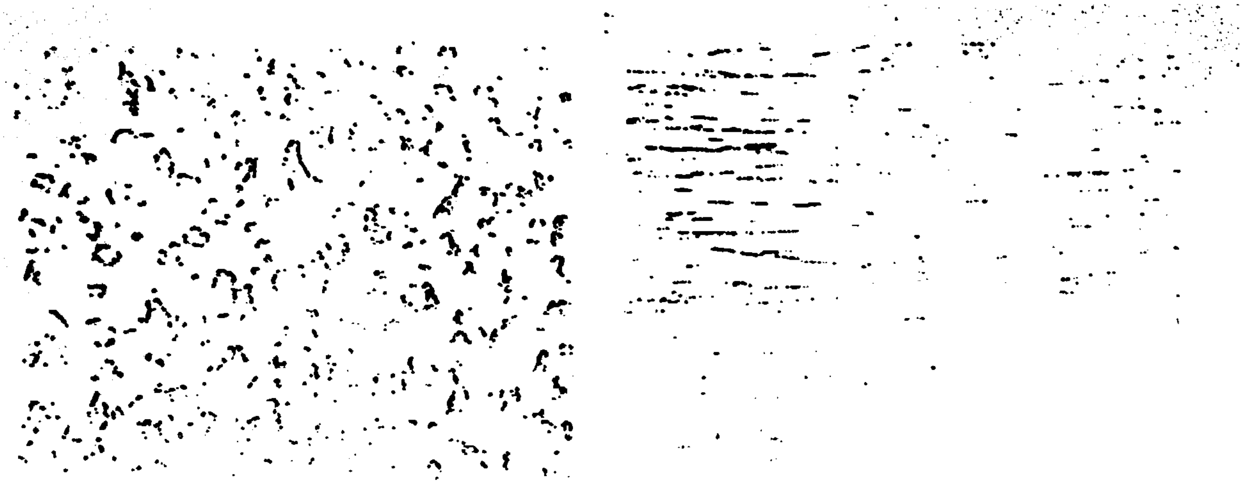
(b)

Figs.15 Al 13,8wt%U alloy. R-40 mm/h. a)Transverse section, 300 x. b)Longitudinal section, 250 x.

(16)

(17)

Fig.16 UAl4 in the eutectic Al UAl4. Selective Etch, SEM. Al 12wt%U alloy. R 10 mm/h. 20000 x.
Fig.17 Al 14wt%U alloy. R 400 mm/h. Transverse section, Etch-HF, 250 x.



Figs.18 Al 20,[illegible] alloy.R=1 mm/h.Etch:HF.a)Transverse section.200 x.b)Longitudinal section.70 x.

Fig.19 ThAl3 morphology in eutectic presented in Fig. 18.Selective Etch.[illegible],000 x.

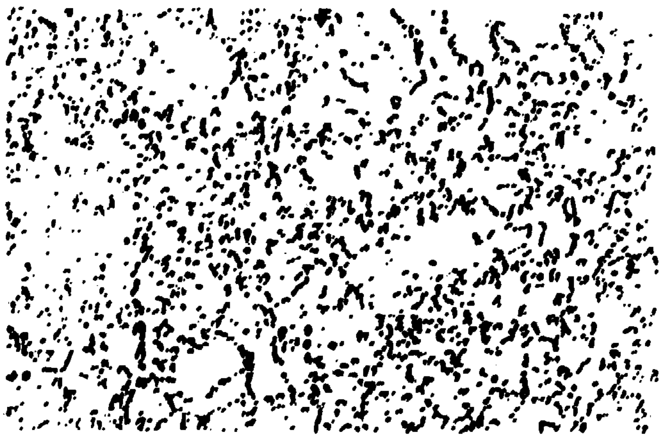


Fig.20 Al 20,[illegible] alloy.R=100 mm/h.Transverse section. Etch:HF.[illegible] x.