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Magdy Kassem
Assistant Professor of Department of Metallurgy, Faculty of Petroleum & Mining Engineering, Suez Canal University, Suez, Egypt.

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Stages of Mechanical alloying of Al-20 wt % Si

مراحل السبك الميكانيكى لسبيكة *Al-20 wt % Si*

Magdy A. Kassem

Dept. of Metallurgy Faculty of pet. & Min. Eng., Suez canal Univ., Suez Egypt.

خلاصة :

تم إستخدام مسحوق كل من الألمنيوم والسيليكون النقى لإنتاج سبيكة الألمنيوم ٢٠٪ سيليكون بواسطة السبك الميكانيكى وذلك بخلط كل من البودرة مع كور من الصلب المقسى بنسبة ١ : ١٠ بالوزن وتقليبها بشدة فى جو من الأرجون الخامل بواسطة مضرب (Attritor) .

أثناء إصطدام الكور سويا ولمرات عديدة فعندما يقع حبيبات البودرة بين كرتين تلتحم الحبيبات سويا (Cold welding) وتعود وتتكسر (Fracture) عند إحتباسها بين كرتين مرة أخرى وذلك لحدوث التصلد بالتشغيل (Work hardening) وتتكرر هذه العملية لمرات عديده إلى أن نحصل على السبيكة والحجم المناسب للحبيبات .

هذا وقد تم دراسة تأثير زمن الطحن على حجم الحبيبات لكل من السيليكون والألمنيوم وكذلك على تكون سبيكة الألمنيوم سيليكون . وقد أمكن إنتاج سبيكة ٢٠٪ سيليكون وبحجم حبيبات سيليكون صغير جدا وبتوزيع فائق التجانس . وقد إستخدمت أشعة إكس وكذلك (DTA) لدراسة التغيرات المختلفة التى حدثت أثناء عملية السبك الميكانيكى.

Abstract:

Aluminum and silicon powders were used to produce Al-20% Si with a very fine dispersed silicon particles in aluminum by mechanical alloying. During milling, the silicon particles fractures and gets impeded in the soft aluminum matrix. Repeated welding and fracture of the aluminum particles inhance the homogenity of the alloy. The effect of milling time on the powder morphology and silicon particles size have been studied. The silicon particle size decreases with increasing the milling time

The X-ray maping and x-ray diffraction were used to measure the distribution and size of silicon particles. DTA was also used to investigate the alloying process.

Introduction:

Silicon is extensively used as an alloying element in the commercial aluminum casting alloy. One of the most attractive properties of the hypereutectic Al-Si alloys is the high temperature dimensional stability. Such dimensional stability is attributed to the dispersion of a high volume fraction of Si in the aluminum matrix*(1)*. Modification of such alloys is necessary to improve the mechanical properties. The modification involves the addition of small amounts of elements such as Na or Sr prior to solidification. Sodium is usually added in the metallic state or as Na flouride (NaF) which, decomposes creating inconvenient fumes. Al-Si alloys dispersed with graphite particles produced by casting have been established for applications subjected to friction and wear conditions because of its good seizure*(2)* and galling resistance*(3)*. Mechanical alloying (MA) can be used to control and refine the microstucture of aluminum silicon alloys. MA was first developed to produce oxide-dispersion strengthed (DOS)-base superalloys*(4)*. Recently MA is used for producing composite metal powders with controlled and extremely fine microstructure. Reducing grain size promotes ductile behaviour in ceramics*(5)* and low temperature superplasticity in alloys*(6)*. Submicrometer grained material alloys produced by severe plastic deformation have been of a large interest. These materials can be produced in large amounts*(7)*. It can also be used to produce alloys which is difficult to produce by conventional melting and casting techniques such as alloys with immicible components or with very large difference in melting point*(8)*. Mechanical alloying can be described as the repeated welding, fracturing, and rewelding of a mixture of powder particles in a highly energetic ball charge. A balanced fracture and cold welding should be achieved for successful mechanical alloying. This balance depends on the alloy system and sometimes a processing agent has to be added. The processing agent reduces excessive cold welding in ductile systems*(9)*. Cold welding was also reduced by cooling the mill chamber. There are several devices used for mechanical alloying such as attritors, vibratory mills and horizontal ball mills.

Dispersion strengthed aluminum alloys produced by (MA) exhibited excellent mechamical properties at temperatures close to their melting points *(10)*. Mechnical alloying also improved strength of Al-Mg alloy 5083 which has excellent corrosion resistance but relatively low strength *(11)*.

Experimental:

Elemental powder of aluminum and silicon was milled in a small attritor using martensitic stainless steel balls 5/16 in. under argon atmosphere and the ball to powder weight ratio was 10/1. Al-20 % Si and Al-20% Si-0.5%C were milled for up to 3 hours. The powder was then cold compacted and sintered in a salt bath for up to 3 hours at 460 C°.

The as milled powder was examined using X-ray diffraction measurements in a Ge-XRDS diffractometer (Cu-k α-radiation). The differential thermal analysis (DTA) was also used to study the microstructural developments during mechanical alloying. Metallographic specimens were prepared by mounting lose powder, green compacted and sintered powder. The mounted speciemens were then carefully grinded and polished. Optical microscopy, scanning electron microscopy (SEM) and energy dispersive X-ray were used to study the microstructure and chemical composition of the processed powder.

Results and Discussion:

The morphology and metallographical changes of mechanically alloyed Al-20 wt. % Si powder are presented in figs (1 and 2) as a function of the milling time. The effect of the milling time on the size of the powder particles is also presented. During the early stages of milling (30 min) the Al particles tend to agglomerate together due to the cold welding, as displayed in fig. (1-a). After 60 min. of the milling time most of Al particles have been elongated and tend to get plate or flake-like morphology, as presented in fig. (1-b). This morphology is attrituted to the repeated ball-powder-ball collision. Increasing the milling time (180 min.) leads to the increase of cold working due to the severe deformation. The plate like particles transforms to an irregular or equiaxed particles as shown in fig. (1-c) due to fracture. At early stages of milling the brittle silicon particles get trapped between the ductile Al particles. On the next stage of milling the Al particles deforms to flake like but the trapped Si particles fractures to smaller size and forms a composite structure with the ductile Al. When the ductite Al work harden and fractures in the course of milling silicon particles get more finer and more homogenously distributed as shown in figs (2a,b,c). The microstructure of the mechanically alloyed (180 min.) and sintered (460°C for 120 min.) Al-20 wt. % Si alloy which show the fine uniform silicon distribution is shown in fig. (3a). X-ray mapping of the sintered alloy shown in fig. (3b) reflects the very fine and uniform distribution of silicon which is very difficult to achieve by conventional processing of Al-Si alloys. The reduction of grain size promotes ductile behavroir, therefore, mechanically milled alloy is expected to exhibit ductile fracture mode. The hardness indentation of the mechanically alloyed and sintered alloy shown in fig. (3c) showes no radial cracks around the hardness indentation which could be taken as a measure of good fracture toughness(11).

X-ray diffraction pattern of the milled powder presented in fig. (4a) does not show drastic changes other than the drop in intensity and broadening of the diffracted peaks with milling. The major peaks are reflected from the Al matrix and Si dispersoids. The X-ray diffraction patterns were used to monitor the cystallites size change of both Al and Si with milling. The Scherrir equation was used to calculate the particles size. The Al particle size changes from 84 nm (after 30 min. milling) to 30 nm (after 180 min. milling) as shown in fig. (4b). However, the silicon size changes from 52 nm to 28 nm for the same milling times.

Differential thermal analysis (DTA) of the mechanically milled powder reflects the effect of milling time on the alloying process. As the milling time proceeds the silicon particles get finer and more unifonnely distributed in the matrix. At early stages of milling (30 min.), the DTA thermogram (on heating) shown in fig. (5a) shows an endothermic peak at 640°C which is close to the melting point of aluminum. With increasing the milling time to 180 min. the endothermic peak gets closer to that of the eutectic reaction of Al-Si alloys (577°C). This trend indicates that the 180 min. milling has formed the eutictic Al-Si, since milling reduces the diffusion distance. The DTA thermogram of the Al-20 wt.% Si milled for 180 min. shown in fig. (5b) also shows a wide exothermic peak from 250° C. This peak could be attributed to the precipitation of silicon dissolved in ∝-Al due to the extension of solid solubility by mechanical alloying, since, ∝-aluminum dissolves almost no silicon up to 400°C at equilibrium.

Conclusion :

Mechanical alloying of aluminum 20 Wt% Silicon has resulted in the formation of a composite structure with a very uniform distribution of very fine Silicon (hard phase) in the aluminum matrix. Milling for 180 min was enough to form the eutictic alloy.

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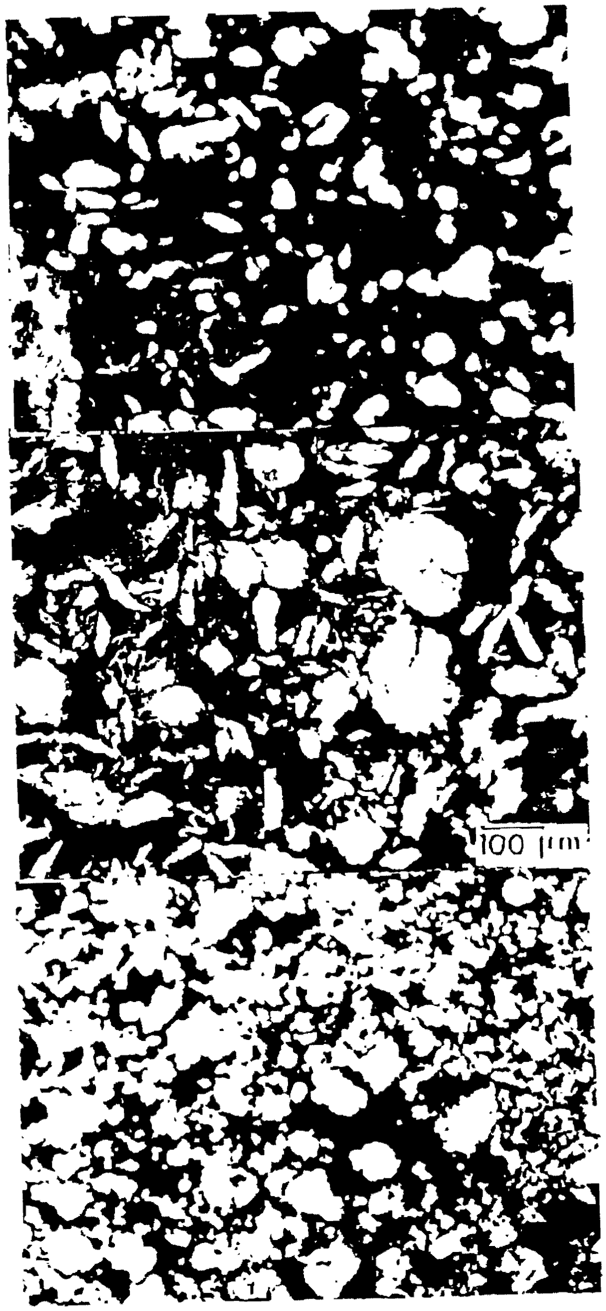
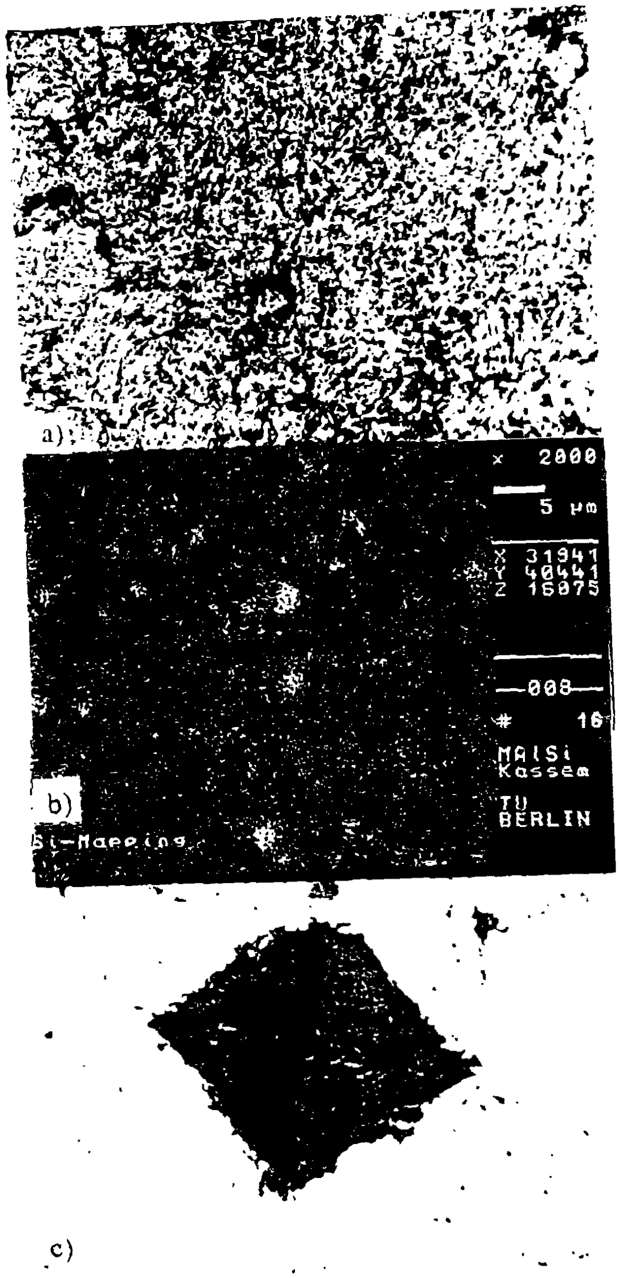


Figure (1) Morphology of MA powder

Figure (2) Microstructure of MA, Al 20 Si cold compacted powder



Figure(3)

(a) Homogenous, fine silicon particles after 180 min. MA and sintering (120 min. / 460 C°) .

(b) Silicon X-ray mapping of MA and Sintered Powder.

(c) Hardness indentation of the sintered Powder (no radial cracks).

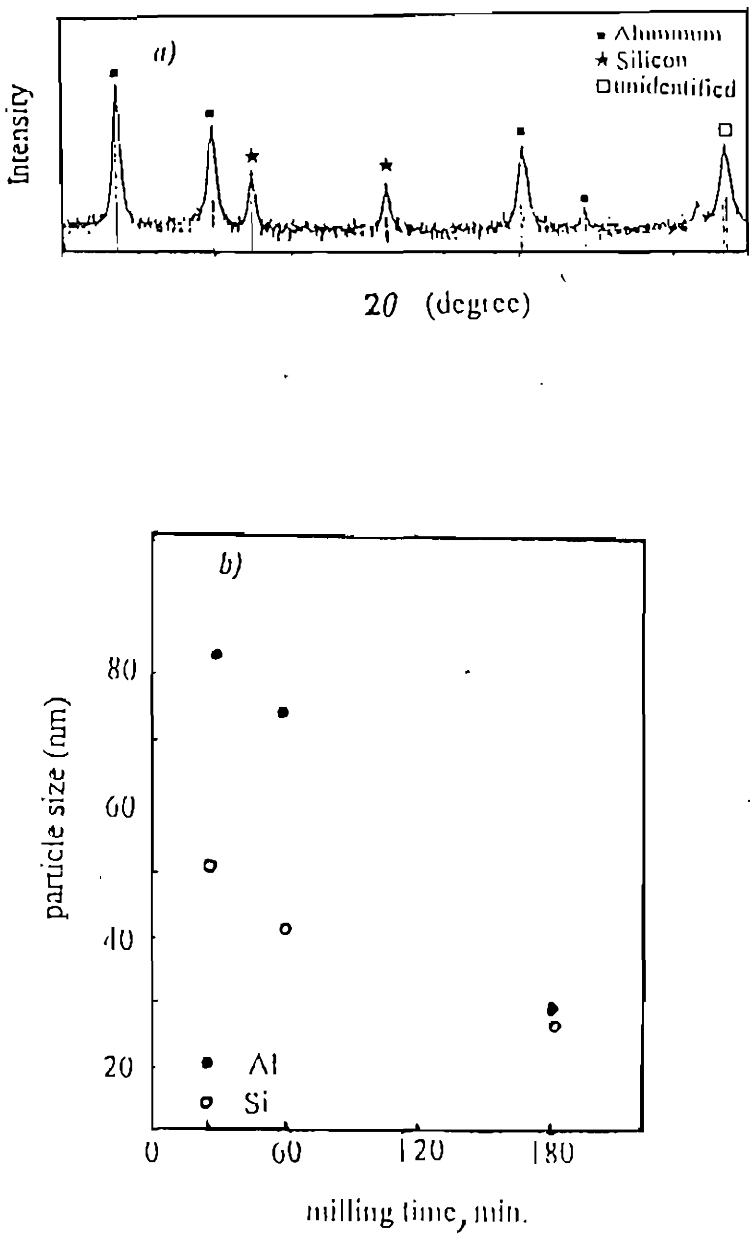
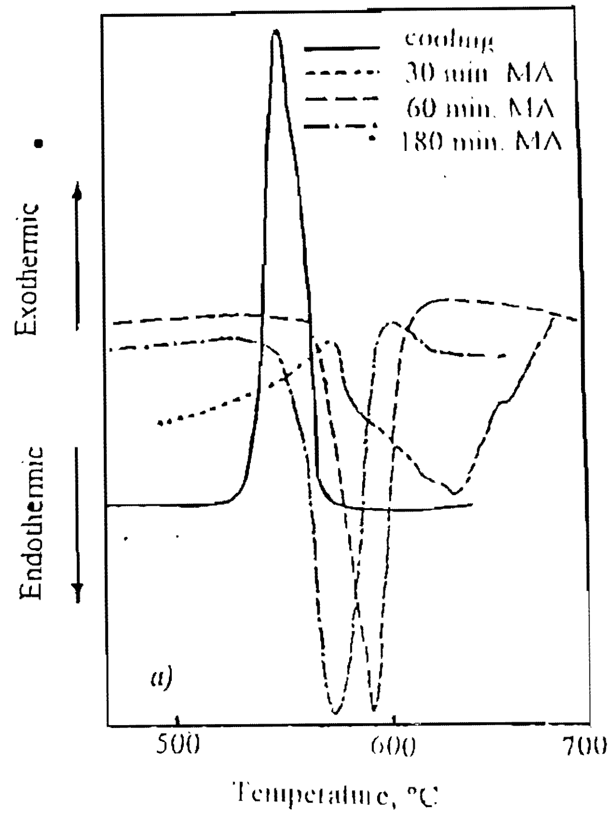


Figure (4) (a) X-ray diffraction of as mechanically powder (180 min.)

(b) Effect of milling on the powder particles size .



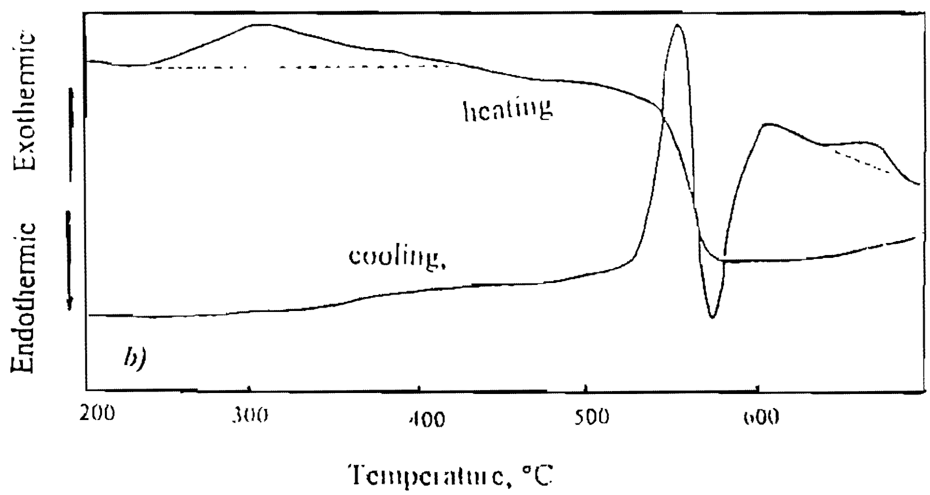


Figure (5) (a) DTA thermogram showing the effect of milling time.

(b) DTA thermogram of as mechanically powder (180 min.).