The Iraqi Journal For Mechanical And Material Engineering, Vol.13, No.2, 2013

INFLUENCE OF GRAPHITE AND SOLIDIFICATION UNDER VIBRATION ON MECHANICAL AND MACHINING PROPERTIES OF HYPEREUTECTIC (AL-SI) ALLOY.

Dr. Haydar Al-Ethari
Babylon University
College of Material's Engineering
Dept of Engineering Metallurgy

Elaf Abdulwahid Hasani
Babylon University
College of Engineering
Dept. of Material'

Abstract:

Hypereutectic aluminum–silicon (>13%Si) alloys have been used for many engineering applications due to their properties. A continuing problem with these alloys is that they are difficult to machine, tool wears rapidly due to the hardness and abrasive nature of the Si particles, so repairing this problem is very important. In this work, the hypereutectic Al-Si alloy samples were prepared by stir casting. Effect of solidification under mechanical vibration with three frequencies (32.5, 100, 124.5Hz) and constant amplitude (0.5 mm) as well as an addition of 0.3% graphite was studied. Several mechanical, physical, and machineability tests were carried out. Machineability tests were related to the surface roughness and tool life. A maximum width of flank wear of 300μm was considered as a criterion of tool life. Carbide tips type P10 with dry turning operations were used at a constant depth of cut of 0.5 mm. Four cutting speeds (15, 21, 31, 45m/min) for each of which four feed rates (0.005, 0.008, 0.01, 0.016 mm / rev) were used as the machining conditions. Results showed that adding (0.3% Graphite) to hypereutectic (Al–Si) alloy accompanied with solidification under vibration improves its microhardness by (26%) and tensile strength by (102%) and modulus of elasticity by (20%). The results of machining experiments showed depressing in tool flank wear and improving surface finish. This was true for all regarded machining conditions. The surface roughness was reduced by (**20-38**%) with the used machining conditions, while an increase of (**76 -94**%) in tool life was achieved.

تأثير الكرافيت والتجميد تحت الاهتزازات على الصفات الميكانيكية والتشغيلية لسبيكة المنيوم–سليكون فوق اليوتكتك.

الخلاصة:

تُستخدم سبائك المنيوم–سليكون فوق اليوتكتك (>13%Si) في الكثير من التطبيقات الهندسية لصفاتها العالية. المشكلة المستمرة لهذه السبائك هي صعوبة تشغيلها، إذ أن عدة القطع تبلى سريعا للصلادة وللطبيعة الحاكة لدقائق السليكون، لذا فان معالجة هذه المشكلة غاية في الأهمية. في البحث الحالي حُضِّرت نماذج لسبيكة الألمنيوم–سليكون فوق اليوتكتك بالسباكة مع تحريك المنصهر. تم دراسة تأثير التجميد تحت تأثير الاهتزازات الميكانيكية باستخدام ثلاث ترددات هي (32.5, 100, 124.5Hz) بمدى ثابت (0.5 mm).

وإضافة الكرافيت نسبة (0.3%). أُجريت عدة فحوصات ميكانيكية وفيزياوية وتشغيلية. مُثّلت الفحوصات التشغيلية بخشونة الأسطح وبعمر عدة القطع. أعتبرت قيمة (300μm) لعرض البلى الخلوصي معيارا لعمر العدة. أُستعملت لقم كاربيدية نوع P10 وعمليات خراطة جافة بعمق قطع ثابت مقداره (0.5mm)، كظروف قطع اعتمدت اربع سرعات للقطع (15, 21, 31, 45m/min) لكلٍّ منها اربعة معدلات للتغذية (0.005, 0.008, 0.01, 0.016 mm / rev). أظهرت النتائج بان إضافة (0.3% Graphite) إلى سبيكة الألمنيوم-سليكون فوق اليوتكتك مصحوبة بالتجميد تحت الاهتزازات يزيد صلادة السبيكة بنسبة (26%) ومقاومة الشد بنسبة (102%) وثابت المرونة بنسبة (20%). أظهرت نتائج تجارب التشغيل انخفاضا في بلى العدة الخلوصي وتحسنا في الإنهاء السطحي لهذه السبائك في جميع ظروف التشغيل المعتمدة. انخفضت خشونة الاسطح بنسبة (20-38%) في ظروف التشغيل المعتمدة بينما تم التوصّل إلى زيادة بنسبة (76 -94%) في عمر العدة.

1. INTRODUCTION:

Hypereutectic aluminum–silicon (>13%Si) alloys have been used for many lightweight, high-strength applications such as internal combustion engine parts, due to low thermal expansion, high hardness, and good wear resistance. Al-Si alloys differ from the "standard" phase diagram in that there is no β phase and so this phase is "replaced" by pure silicon. So, for Al-Si alloys, the eutectic composition is a structure of α+Si rather than $\alpha + \beta$ [1,2]. Hard and highly abrasive primary particles of non-metallic silicon are embedded in an Al-Si eutectic matrix. Silicon crystal hardness ranges from 1000-1300 KHN, while that of the alloy matrix seldom exceeds 180 KHN [3,4]. So Increasing silicon increases strength at the expense of ductility [5] and significantly impact the machineability [6]. The mechanical properties of cast component are determined largely by the shape and distribution of Si particles in the matrix [7]. Primary silicon in hypereutectic Al-Si alloys may appear in several different morphologies, and it is not uncommon to find many of these in the same casting. The morphology of silicon in hypereutectic alloys is highly dependent on the cooling rate [1]. Hypereutectic Al-Si alloys also suffer from macro-segregation, particularly under slow solidifications conditions. Higher mechanical properties in these alloys can be achieved by controlling the grain size, and solidification parameters such as the cooling rate. The preferred structure of a casting is one that has small equiaxed grains which can be achieved through control of the solidification conditions or by grain refinement [8]. Modification in a casting of hypoeutectic Al-Si alloys is mainly associated with the alteration of the silicon phase. Modification induces a transition of the primary silicon involving three apparent possibilities: irregular to dendritic, irregular to spheroidal, and dendritic to spheroidal [1,3].

Hypereutectic Al-Si alloys are the most difficult to machine among the various aluminum alloys, so repairing this problem is very important. Tool wears, very rapidly. Flank wear is often used to define the end of effective tool life. Flank wear affects on surface finish, and increase both cutting force and temperature. Tool life can be quantified by a certain level of the surface roughness or by putting a limit on the maximum acceptable width for the flank wear (VB). Surface roughness is an important measure of product quality , has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life, etc.

Many papers related to the improvement of hypereutectic Al-Si alloy had been published. The influence of a vibration treatment for the process of the solidification and the effect on mechanical and physical properties of the eutectic alloy AlSi12 and AlSi12.5 and hypereutectic Al-Si alloy had been studied in [9, 10, 11, 12]. The influence of vibration on the size and morphology of α-Al phase of a lost foam cast (LFC) 356 aluminum alloy had been studied in [13]. Tool wear and surface roughness under different rake angles and different cutting speed were investigated in [14]. Few researches were focused on hypereutectic Al-Si system but with low percentage of Si. Instead of Al-Si alone, researchers studied the effect of adding alloying elements as Cu, Mg… etc. The present work aims at the study of the effect of mold vibration on machineability of the hypereutectic Al-Si system with high percentage of Si with improvement of its mechanical properties. This will be carried out also with the effect of reinforcing the alloy by small amount of graphite particulate.

2.EXPERIMENTAL PART

2.1.Preparation of the Alloy Samples.

Three types of alloy samples were prepared by die casting: hypereutectic Al-Si alloy solidified without vibration, hypereutectic Al-Si alloy solidified under the effect of mechanical vibration, and hypereutectic Al-Si alloy with a small percentage of graphite particulates solidified also under the effect of mechanical vibration. All samples were prepared using high purity aluminum (99.99%). The high purity aluminum was melted in a ceramic crucible at 800°C in an electric furnace type (Via P.da Cannobia, 10, 20122 MILANO, Italy). Silicon (in the form of particles) and graphite (if required) were coated separately by aluminum foil before adding gradually to the melt. During the process the melt was stirred using electric stirrer rotating with a speed of 750rpm. Preheated steel die with a cylindrical cavity of (20mm) diameter and (200 mm) height was used. For casting under the effect of vibrations the die was attached on a system that provides a mechanical vibrations. The obtained samples were heat treated at 200°C for 6hrs for stress relief in an electric furnace type (Sola Basic SB Lindberg).

2.1.1. Preparation of Coated Graphite:

Due to poor wetting of graphite powder with aluminum and difficulty of adding it (as free) to the melt, it was coated with copper by using electroless deposition. The materials used in electroless deposition are listed in table (1). The process of deposition was carried out by solving copper sulfate in hot water and left it to cool, then formaldehyde was added**.** Sodium hydroxide was solved in hot water then Rochelle salt was added to it. The two solutions were mixed to deposit copper. Adding graphite to the mixture caused a change of its color to red, which means that copper coated graphite.

2.1.2. Mechanical Vibration Set up:

Mechanical vibrations were provided using a vibrating device developed and built specially for the present work . Fig. (1) shows a sketch for this device. The device provides the vibrations due to eccentric of a shaft which can be rotated with different rotating speed to get the required frequency. The rotating speed was measured using a (Tachometer/ England). A computerized Vibration Data Collector TV200D [model number 911D, sensor sensitivity 5.oo pc/ m .s] was used to collect the vibrational. The used vibrating conditions are demonstrated in table (2**).**

2.2.Physical and Mechanical tests:

⁎ **Microhardness Test:** Specimens of (20mm diameter × 3mm height) were cut from the treated samples. Appropriate grinding and polishing were carried out before tests. The test were conducted on a Vickers micro hardness testing machine type [TH-717, Digital Micro

Vickers Hardness Tester] using a load of 100g for 20 sec using square-base diamond pyramid.

* **Tensile Test:** Tensile test specimens were prepared from alloy samples according to the ASTM (E8M-04) [15]. All tests were conducted with a low constant speed at room temperature using a computerized universal testing machine type (Gunt / Hamburg).
* **Microscopic Analysis:** The samples were prepared in consistent with the standard metallographic techniques. The sectioned specimens were abraded in a sequence of steps using progressively finer abrasive papers (180, 400, 600, 800, 1000, 1200, 2000 grit size). Grinding has done on polishing machine type (MP200V). Polishing stage was carried out using paste type (nature diamond, with size 15 µm, 6 µm, and 1 µm). Etching treatment for 15 sec in an etchant solution (0.5%HF+99.5% distilled water) [16] was performed by repeated dipping of the sample. Etching would be stopped by immediate washing with distilled water, rinsed with ethylalcohol and dried by air. Standard metallographic examinations were conducted using professional metallurgical microscope with polarizing dark field reflected light model (1280XEQ-MM300TUSB).
* **X-Ray Diffraction Analysis:** The X-ray diffraction analysis covered a selected for all samples. The analysis has been done with the help of professional institute for engineering industries /Baghdad. The measurement conditions are (Target: Cu, wave length of 1.54060 A^o, voltage and current are 40 KV and 20 µA respectively ;and $2\theta = (20 – 80^0)$.

2.3.Machining Experiments:

External turning on cylindrical samples (diameter of 18mm, length of 180mm) was carried out on a lathe type (**Harison / England**/ 2.2KW, spindle speed of 40 to 2500 rpm and feed rate of 0.03 to 1 mm / rev). Prismatic carbide tips type P10 (tool angle of 55°, nose radius of 1.6mm) with a chemical composition of (65% W, 9% Co,26% (Tac +Tic) and dry cutting were used at a constant depth of cut of 0.5mm. Four cutting speeds (15, 21, 31, 45m/min) for each of which four feed rates (0.005, 0.008, 0.01, 0.016 mm / rev) were used as the machining conditions. During the machining operations measurements were related to the tool flank wear and surface roughness.

A maximum width of (VB_{max} = 0.3 mm) for the flank wear was used as a criteria for the tool life according to ISO 3685 [17].One –minute-short time test was considered in measuring the flank wear. Optical microscope type (1280XEQ-MM300TUSB) integrated with CCD camera was used to capture the image of worn tools and to measure the flank wear. The surface roughness was measured after a first minute of machining for each cutting operation. Roughness tester type (TR 200 roughness tester) was used in these measurements.

3. RESULTS AND DISCUSSIONS:

Table (3) demonstrates the chemical compositions of the prepared alloy samples. The analysis had been done in the Professional Institute for Engineering Industries /Baghdad.

3.1. Result of X-Ray Diffraction Analysis: Figure (2) and tables (4) and (5) represent the charts of the x-ray diffraction and the analyzed data due to tests of alloy samples S0 and SG respectively. The results of the XRD tests for all alloy samples show that (primary Si phase) is the only phase created during solidification. The demonstrated charts and data represent examples of identical results of the tests for all alloy samples.

3.2. Result of Microscopic Analysis:

The microstructures of alloy samples are shown in Figure (3). The microstructures consist mainly of primary Si phase in a hypereutectic Al-Si phase. It is clearly shown that solidification with vibration causes refinement as a change in the size and distribution of the primary Si phase. The morphology of primary silicon changes from star shape to fibrous. These results can be explained based on the heat transfer mechanisms both in the liquid phase and in the mould wall interface and its effect on the microstructure. The refinement is dependent on cooling rate which is accelerated due to vibration by transferring the particles from the mold walls towards the center of the casting where they become new nucleation sites, thus increasing the overall nucleation rate at the expense of the growth rate of primary silicon particles. Also, it is a well known fact that growth and coarsening of primary silicon particles continues till the Al-Si eutectic reaction.

3.3.Results of Mechanical Tests:

Table (6) demonstrates the results of microhardness and tensile tests of the alloy samples. From the results, it can be noticed that hardness and tensile properties increases with the increase in vibration frequency due to the refinement of silicon particles. More enhancements in tensile properties and hardness were recorded due to the addition of graphite. This may be due to the role of graphite as a reinforcing particles which impede the motion of dislocation, also little amount of copper make grain size more finer. The recorded hardness are in agreement with [18], while that of tensile test are in agreement with [11].

3.4. Result of Machining Experiments:

The machining experiments were carried out for the alloy samples S0, S3 ,and SG. Results of these experiments are demonstrated in table (7).

Tool Life: Fig (4) shows examples of the wear occurred at the flank surface of the tool during different machining conditions. Fig. (5) represents an example for the typical behavior of the width of the flank wear with the machining time. Fig. (6) shows the relations between the tool life and the cutting speed in accordance with the well – known Taylor equation ($VT^n = C$, where : V- cutting speed (m / min); T- tool life (min) ; n- index of the equation ; and C- constant). Fig. (7) shows the variation of the tool life with the used feed rates under a certain value of the cutting speed.

A higher cutting speed causes a higher value of VB due to increase in cutting temperature which may cause an increase in adhesion wear and a softening of a very thin surface layer of the cutting edge. In addition to that a higher cutting speed means a higher repeated contact between the machined and the flank surfaces and this increases the scratching action of machined material (ie the abrasive wear). Casting under the effect of mechanical vibration increases the tool life in a manner that is independent on the machining conditions due to the changes in morphology of primary silicon to fibrous which makes abrasive wear less happening. An additional increase in tool life was recorded in machining the alloy samples reinforced by graphite, this may be due to the lubricating behavior of graphite.

Surface Roughness: Figure (8) and fig (9) show the variation of the surface roughness with used cutting speeds and feed rates respectively. It can be observed that at a certain feed rate, machining with a higher cutting speeds causes a lower surface roughness and at a certain cutting speed machining with a higher feed rate causes a higher surface roughness.

Casting under the effect of mechanical vibration reduces the roughness of the machined surface with all cutting conditions due to the induced changes in the size , shape , and distribution of the primary Si phase which reduce its abrasive action during machining.

Graphite causes an additional reduction in roughness of the machined surfaces due to its lubricating behavior. Figure (10) shows a micrograph of the surface for each of the alloy sample S0, S3, SG , after machining with a cutting speed of 45 m/ min, feed rate of 0.016 mm /

rev and a depth of cut of 0.5 mm . It is clear that the SG alloy sample has the best surface finish due to accompanying of the mechanical vibration and adding of graphite.

4. CONCLUSIONS:

According to results of present work, the following can be concluded :

1. Using mechanical mould vibration technique during solidification of hypereutectic Al-Si alloy causes refinement of primary Si particles and change in their shape and distribution .
2. Due to solidification under vibration microhardness, tensile strength, and modulus of elasticity of the hypereutectic (Al-Si) had been improved by (**9**%), (56%), and (14%) respectively.
3. Adding (0.3% Graphite) to hypereutectic (Al –Si) alloy and solidification under vibration improves its microhardness by (**26**%), tensile strength by (102%), and modulus of elasticity by (20%).
4. Adding graphite in accompany with casting under vibration highly affect on machining properties of (Al-Si) alloy. The surface roughness was reduced by (20-38%) according to the used machining conditions . The tool life was increased by (76 -94%).

Table (1): Materials used in electroless deposition

Material	**Weight gr / L**
Copper sulfate (cuso4 .5 H2O)	30
Rochelle salt (Nakc4 H4 O6 .4H2O)	135
Formaldehyde (37% by weight)	150
Sodium hydroxide (NaOH)	40

Table (2): vibration conditions.

Alloy code	**Planned composition**	**Motor speed (rpm)**	**Frequencies (Hz)**	**Amplitude (mm)**
S0	Al-18%Si	0	0	0
S1	Al-18%Si	Low, 400	32.5	0.5
S2	Al-18%Si	Moderate, 900	100	0.5
S3	Al-18%Si	Relatively high, 1400	124.5	0.5
SG	Al-18%Si-graphite composite	Relatively high, 1400	124.5	0.5

Table (3): Chemical composition of the samples prepared in this study.

Alloy code	**Weight percentage of the element (%)**									
	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Pb	Sn
S0	Bal	17.3	0.13	0.006	0.001	0.005	0.0	0.002	0.001	0.001

S1	Bal	18.2	0.13	0.003	0.001	0.004	0.0	0.003	0.001	0.001
S2	Bal	17.3	0.13	0.004	0.001	0.004	0.0	0.002	0.001	0.001
S3	Bal	18.7	0.14	0.002	0.001	0.005	0.001	0.002	0.001	0.001
SG	Bal	17.9	0.12	0.539	0.003	0.002	0.002	0.009	0.000	0.001

Table (4): Result of X-ray diffraction analysis for S0 alloy sample.

Peak no.	2Ө	$d_{hkl}(A^0)$	phase	Peak no.	2Ө	$d_{hkl}(A^0)$	phase
1	28.5	3.129	Si	6	65.12	1.4313	Al
2	38.54	2.334	Al	7	69.16	1.3572	Si
3	44.76	2.023	Al	8	76.38	1.2459	Si
4	47.32	1.9194	Si	9	78.22	1.2211	Al
5	56.14	1.637	Si				

Table (5): Result of X-ray diffraction analysis for SG alloy sample.

Peak no.	2Ө	$d_{hkl}(A^0)$	phase	Peak no.	2Ө	$d_{hkl}(A^0)$	phase
1	28.28	3.1531	Si	7	68.98	1.3603	Si
2	38.32	2.3469	Al	8	76.24	1.2478	Si
3	44.58	2.0308	Al	9	78.1	1.2227	Al
4	47.16	1.9256	Si	10	82.38	1.1696	Al
5	55.98	1.6413	Si	11	87.88	1.1101	Si
6	64.98	1.4340	Al				

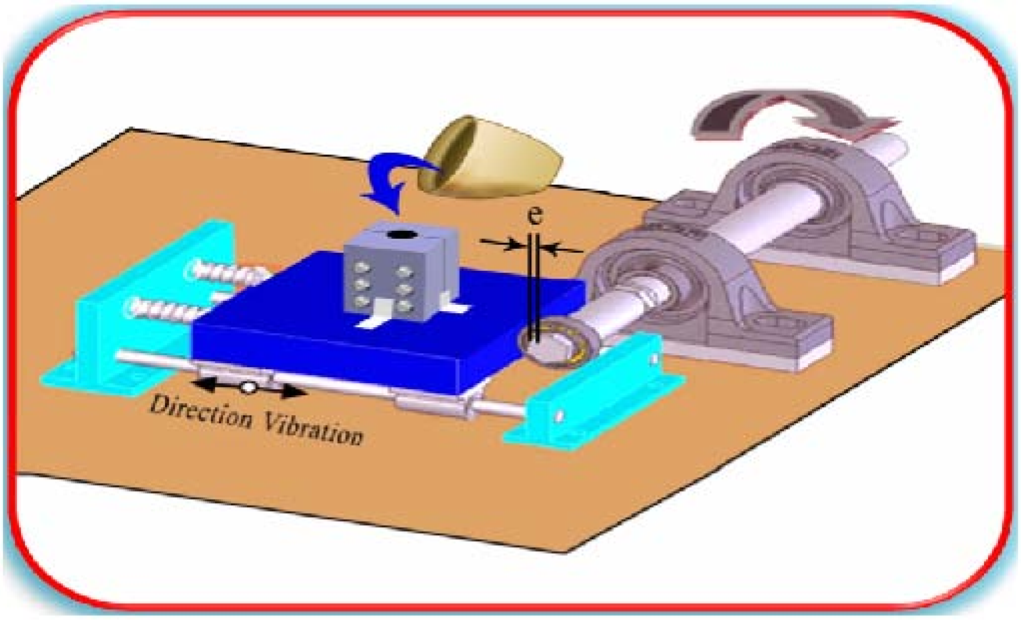
Table (6): Tensile properties of the alloy samples.

Alloy code	Vickers hardness (kg/mm^2)	Tensile strength (MPa)	Maximum Strain %	Modulus of elasticity(Gpa)
S0	94.813	82.88	1.5	80
S1	97.123	111.671	2	84
S2	97.266	126.614	2.25	87
S3	103.146	128.09	4	91
SG	119.6	168.035	3.9	96

Table (7): Result of machining experiments.

Alloy code	Cutting speed (m/min)	Feed (mm/rev)							
		0.005		0.008		0.01		0.016	
		T (sec)	Ra (µm)	T (sec)	Ra (µm)	T (sec)	Ra (µm)	T (sec)	Ra (µm)
S0	15	95.4	5.3	78	5.81	60	6.25	54	6.70
	21	72	4.12	66	4.78	55.2	5.1	48	5.79
	31	60	3.91	53.4	4.51	47.4	4.9	42	5.43
	45	54	3.55	48	3.95	42	4.21	36	4.95
S3	15	96	3.75	84	4.00	69	4.83	71.4	5.01
	21	84	3.50	77.4	4.0	63	4.63	51.6	4.92
	31	72	3.00	60	3.52	54	4.00	48.6	4.53
	45	60	2.95	54	3.35	48	3.87	45	4.32
SG	15	168	3.27	162	3.78	148.8	4.15	137.4	4.83
	21	114	2.96	107.4	3.45	93	4.64	83.4	4.78
	31	108	2.20	87	2.48	75	3.22	57	3.99
	45	105	2.83	66	3.2	54	3.40	51	3.80

T- Tool life & Ra- Surface roughness



Fig(1):Vibration instrument , e: eccentricity.

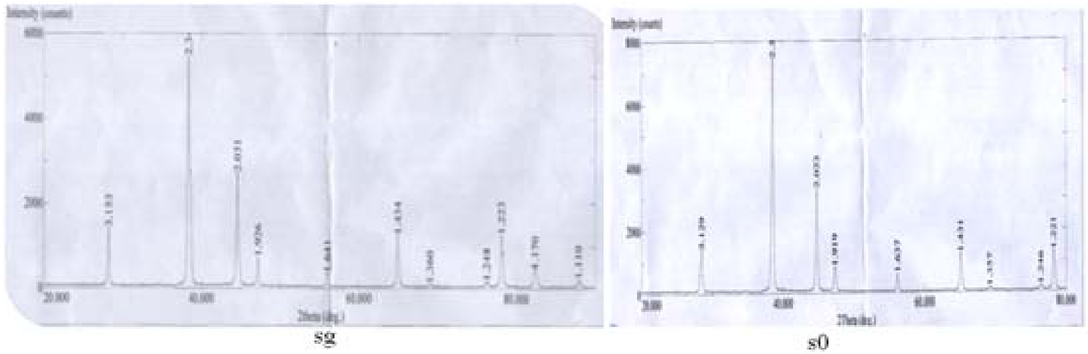


Fig (2): Result of X-ray diffraction analysis for S0&SG alloy samples.

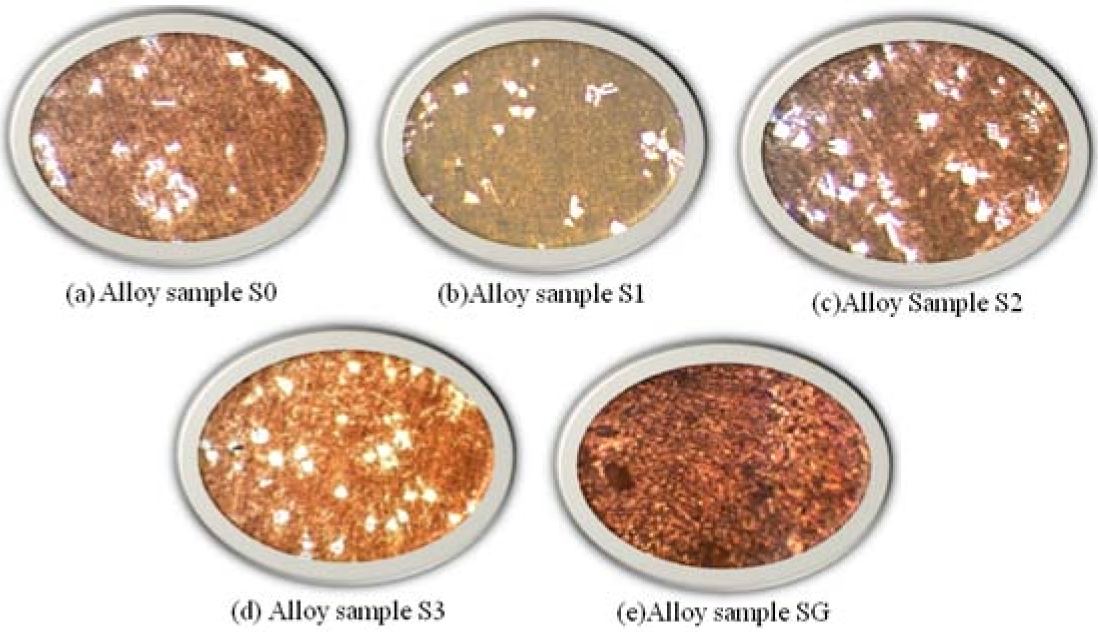


Fig.(3): Optical microscopy of the alloy samples (x100).

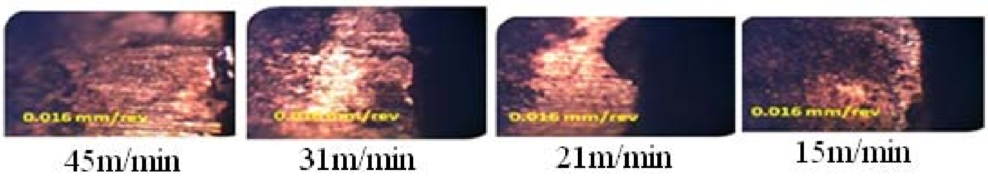


Fig.(4): Flank wear during machining of the alloy sample So (x100)

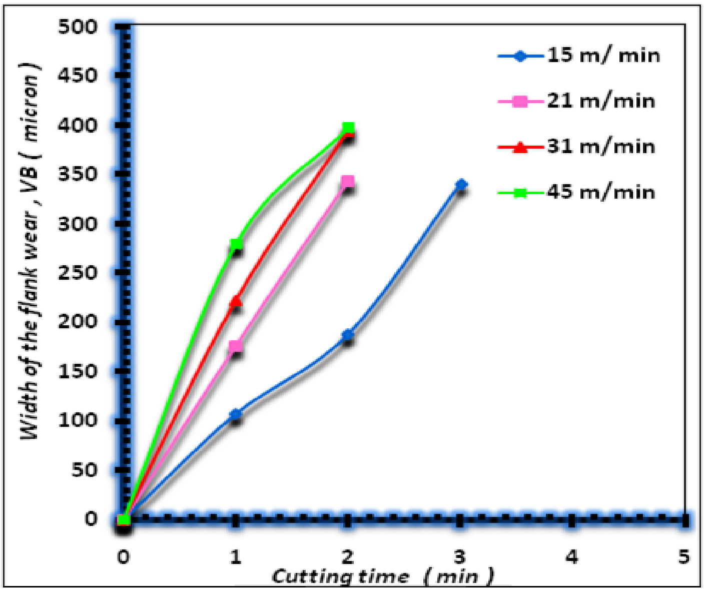


Fig (5): Relation between the width of the flank wear and the machining time (alloy sample: SG, feed rate = 0.008 mm/ rev, depth of cut of 0.5 mm).

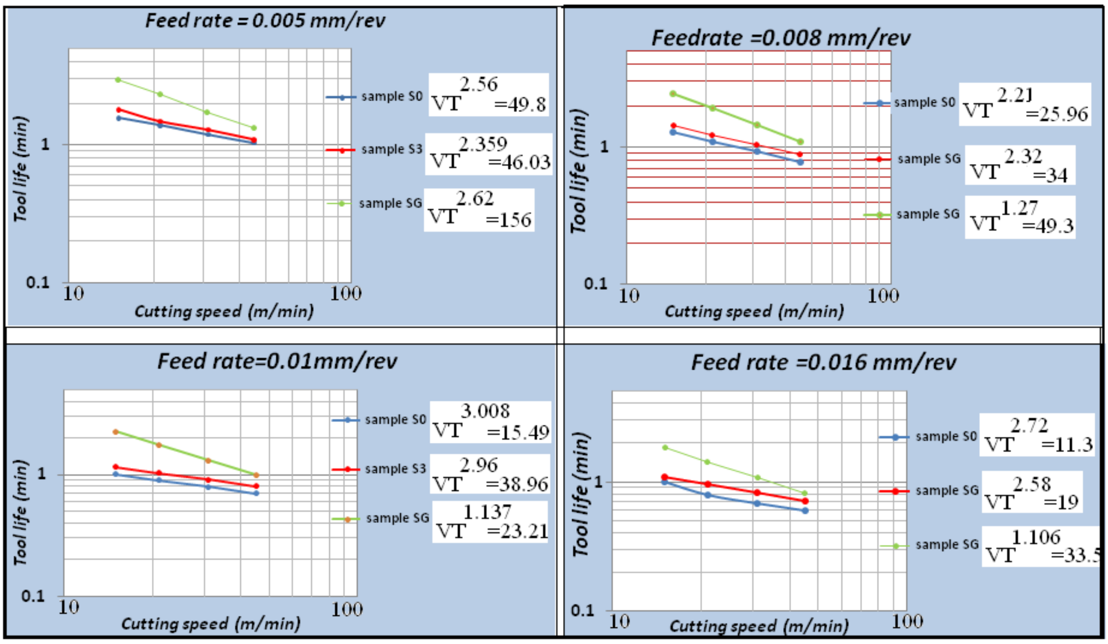


Fig (6) : Effect of mechanical vibration and graphite on the tool life used in machining with a feed rate of 0.016 mm/rev and various cutting speed.

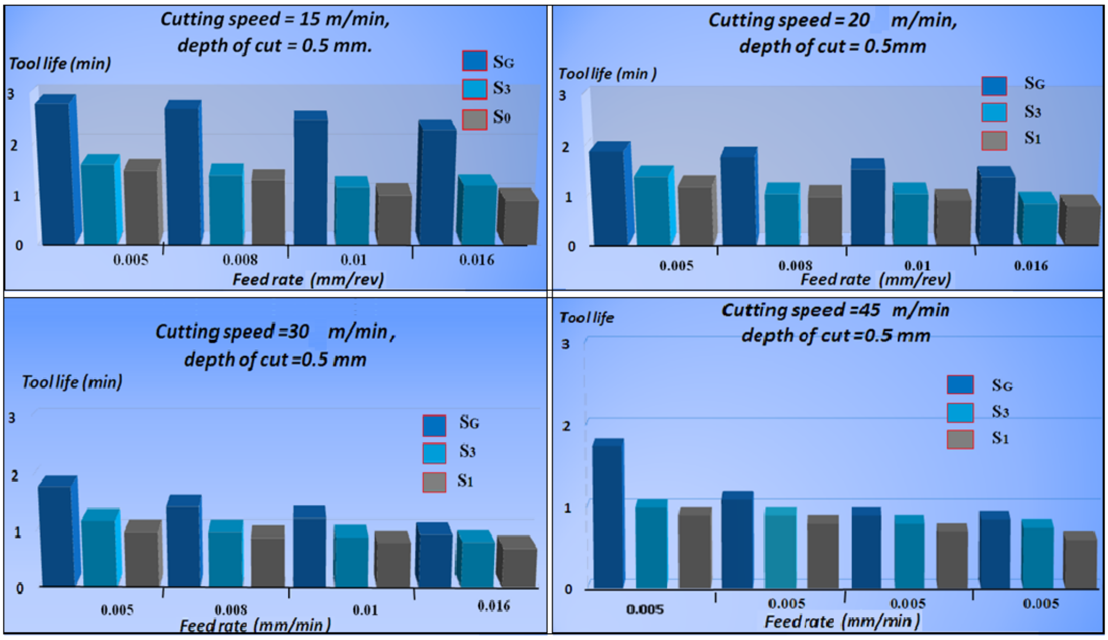
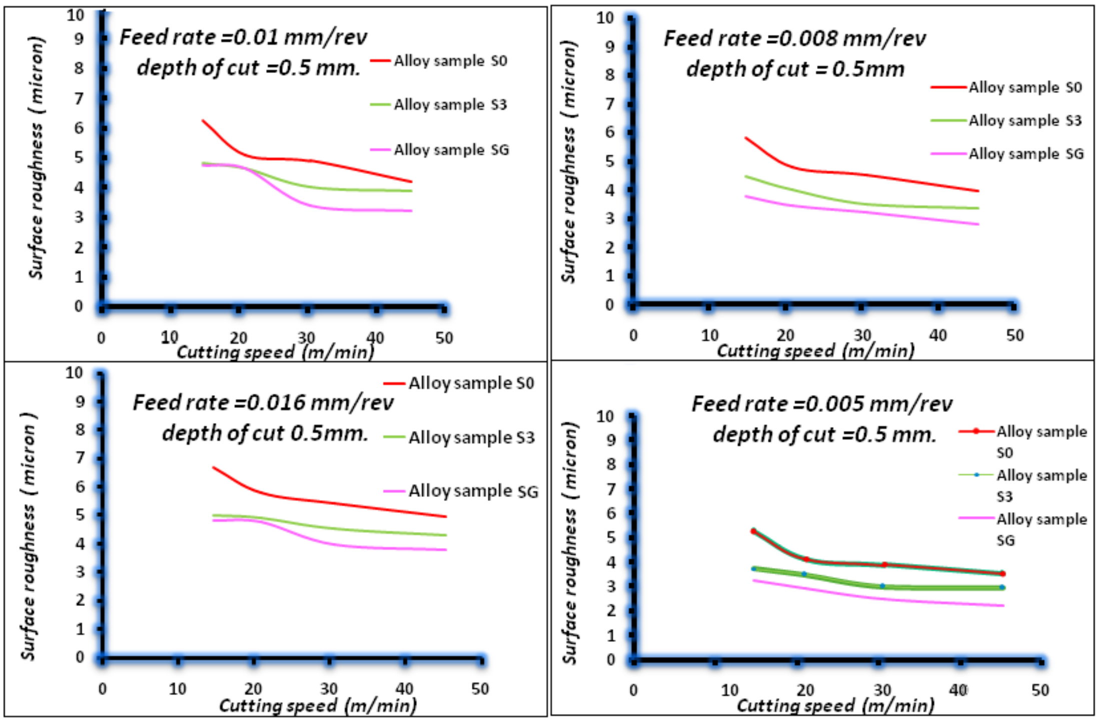
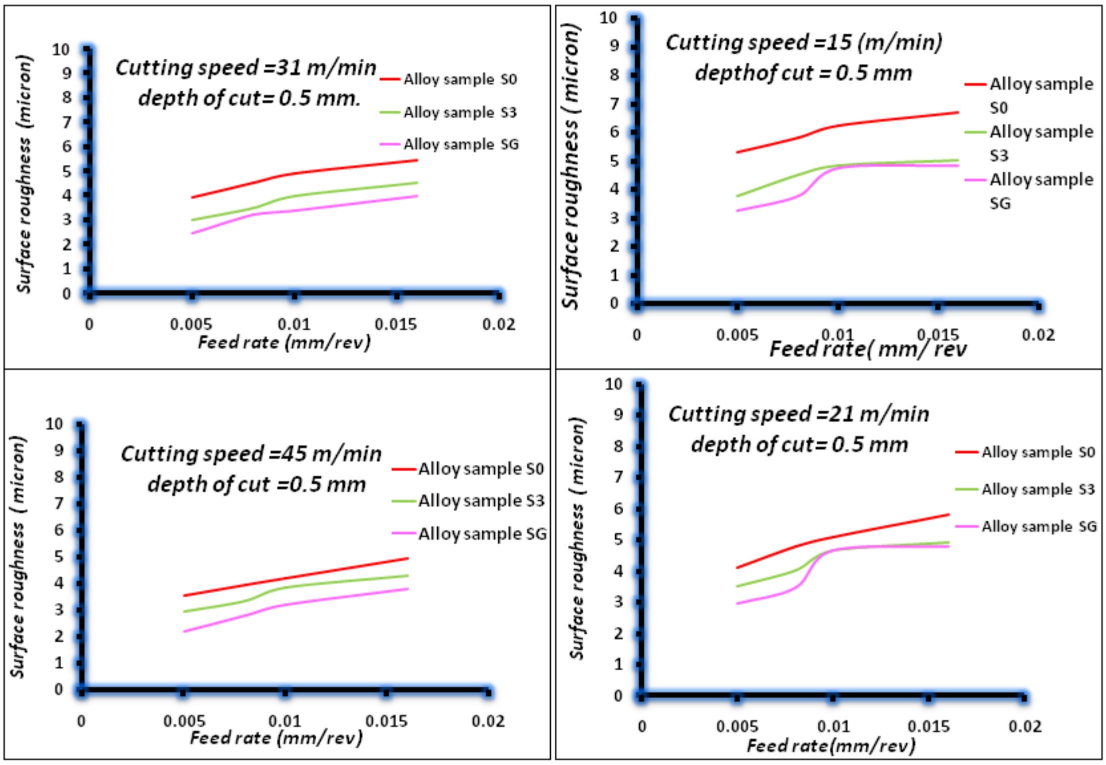


Fig (7): Effect of mechanical vibration and graphite on the tool life used in machining with various cutting speed.



Fig(8): Effect of mechanical vibration and graphite on roughness of the machined surface with various cutting speed and a feed rate of 0.005, 0.008, 0.01, 0.016 mm/rev .



Fig(9): Effect of mechanical vibration and graphite on roughness of the machined surface with various feed rate and a cutting speed of 5, 21, 31, 45 m/min .

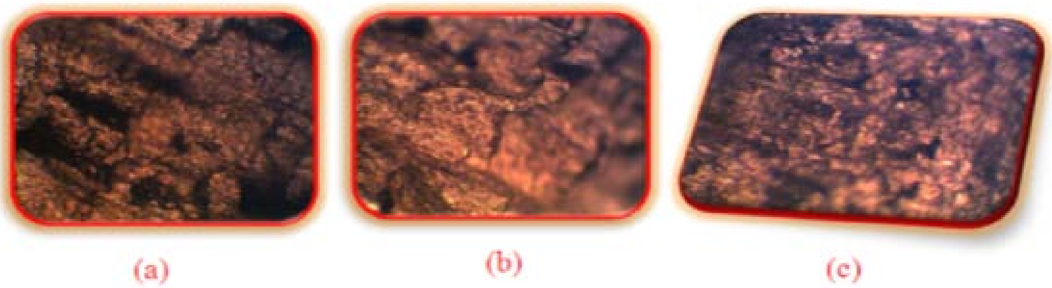


Fig (10) :Micrograph (400 X) of machined surfaces, a cutting speed of 5 m/min and a feed rate of 0.016mm /rev for the alloy sample , (a) S0 where Ra= 4.957, (b) S3 where Ra= 4.32 , (c) SG where Ra= 3.2µm .

REFERENCES:

Avner, Sidney H,1974, " Introduction to Physical Metallurgy" , McGraw- Hill.

Awham Jumea Salman , 2009, " Experimental Analysis of In- situ Composite Al-Si Eutectic Alloy ", MSc thesis, University of Babylon.

Bast J. Hübler, Dommaschk C., 2004, "Influence of Vibration During Solidification of Molten Metal on Structure and Casting Properties", Advanced Engineering Materials.

Castero G., Almeida F.A. , Oliverira F.J. , Fernande A.J.S,.Sacramento J, Silva R.F. , 2008 " Dry machining of silicon –aluminum alloys with CVD diamond brazed and directly coated Si 3N4 ceramic tools, Vacuum",. journal homepage : www. Elsevier .com /locate / vacuum .

Chirita G., 2009, " Influence of vibration on the solidification behavior and tensile properties of an Al–18 wt%Si alloy " , Materials and Design, 1575–1580.

Erry Yulian T. Adesta, 2009, "Tool Wear and Surface Finish Investigation in High SpeedTurning Using Cermet Insert by Applying Negative Rake Angles" European Journal of Scientific Research, Vol.38, pp.180-188.

Forge Saeid, Moftaah Saeid, 2007, "Effect of material structure of machining characteristics of hypereutectic Al-Si alloy", MSc thesis, University of Technology, Malaysia.

ISO- 3685, 1977, " Tool Life Testing with Single Point Turning Tools".

Joonyeon Chang, , 1998, "Refinement of cast microstructure of hypereutectic Al-Si alloys through the addition of rare earth metals", Journal of Material Science , pages (5015 – 5023).

Mahmoud M .Tash, 2005 ,"Effect of Metallurgical Parameters on The Maching Behavior of 356 and 319 Alloys (Drilling And Tapping Study)", MSc Thesis, Malaysia.

Numan Abu-Dheir, Marwan Khraisheh, , Kozo Saito and Alan Male, 2005, " Silicon morphology modification in the eutectic Al–Si alloy using mechanical mold vibration ", Materials Science and Engineering ,Volume 393, pages(109-117).

Umesh Khandey, 2008, "Optimization of Surface Roughness ,Material Removal Rate And Cutting Tool Flank Wear in Turning Using Extended Taguchi Approach", MSc Thesis National Institute of Technology, India.

Sami Salama Hajjaj ,2007 , " A Study on Machining Characteristics of Strontium Modified LM-6 Alloy" , MSc. thesis` , International Islamic University , Malaysia.

Shikun Xie , Rongxt Yi, 2011, "Process of Equiaxed Grains of RE-AI Alloy under Slope Vibration", Advanced Materials Research ,Vols. 146-147 , pp 349-352.

Smallman R.E. and Bishop R.J., 1999, "Modern physical metallurgy and materials engineering science, process, applications" Sixth edition, Butterworth-Heinemann, Britain.

Takio Tanaka and Shinsaku Hanaski , 2006, " Effects of the adding of Cu and Mg on the machineability of hypereuetectic Al-Si system alloys ", Materials Science and Engineering ,(207-217).

Zhao Zhong, Fan Zitian, Dong Xuanpu, Tang Bo, Pan Di and Li Jiqiang , 2010, "Influence of mechanical vibration on the solidification of a lost foam cast 356 alloy ", China Foundrt, Vol.7 .