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Prepared Thixoforomed Aluminum Alloys by High-Pressure Cast and Study Their Wear Propertie

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ABSTRACT - Hypereutectic Al-Si casting alloys are attractive candidates for connecting rod applications in compressors. Several hypo- and hypereutectic Al-Si alloys were produced by pressure die casting and thixoforming in this search. Hypereutectic Al—Si alloys were less than the near-eutectic and hypoeutectic alloys under the sever were conditions encountered in compressors, confirming the impact of Si on were resistance. Cu also improves were properties. The thixoformed alloys were at comparable rates with pressure die cast alloys at lower Si levels, implying that the lower Si content of the former is compensated for by the thixoforming processing route. Hypereutectic composition, uniform dispersion of fine Si particles and thixoforming as the production route are all good for a superior wear performance, However, does not translate into a sizable improvement in wear resistance of the thixoformed alloys.

***Keywords*: -: -** Thixoforming; Aluminum alloys casting; sliding wear.

1. INTRODUCTION

Forced to manufacture energy-efficient products due to environmental concerns, manufacturers of refrigerators and air conditioners have to use compressors with high-performance in their products. One of the practices to achieve better performance in compressors is to use lubricants with lower viscosity. However, low-viscosity lubricants give thinner oil films between the connecting rod and the wrist pin allowing increased metal/metal contact and heavier wear problems in connecting rods.

This change in the boundary lubrication conditions in service dictates requirement for a material with superior wear properties. Hypereutectic Al-Si alloys which offer high wear resistance, high strength, high hardness and low thermal expansion (l,2), are thus attractive candidates. These attributes, together with excellent castability and reduced density, make these alloys very competitive in heavy wear applications (3). Hard silicon particles distributed throughout the aluminum matrix are responsible for the outstanding wear resistance (3). However, the use of these alloys in conventional cast grades has been somewhat restricted owing to their high latent heat and consequent long solidification time which results in die wear, segregation and excessive growth of primary silicon particles, and unfavorable shrinkage behavior (4.5).

Thixoforming was recently considered to be a viable alternative in the production of these alloys, as it can help to overcome these adversities (4-6). In thixoforming, the casting temperature and heat content are very much reduced, the time available for coarsening of the primary silicon is minimized and the shrinkage is much less than that of a molten alloy (6). The present work originated from a need for a material more resistant to wear than the present HPDC near-cutectic Al-Si alloy for connecting rod applications in compressors. Two remedies were considered in the present work. The first was to replace the present HPOC Al-Si alloy with hypereutectic Al-Si alloys with improved wear resistance. While investigating the wear properties of several Al-Si alloys, it was judged to be worthwhile also to explore thixoforming as an alternative processing route. This paper reports the wear behavior of hypo- and hypereutectic Al-Si alloys produced with high-pressure die casting and thixoforming tested under conditions which prevail in connecting rod applications in compressors.

2. EXPERIMENTAL

The chemical compositions of the aluminum alloys used in this study arc listed in Table (1).

Table(1):- Chemical composition of the alloys used in the present work HPDC, high-pressure die cast; TF, thexoformed.

alloy	route	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn
1		12.10	1.096	2.167	0.258	0.091	0.026	0.097	0.894
2		18.21	0.708	1.988	0.077	0.456	0.011	0.509	0.437
3		20.27	0.351	3.535	0.041	0.692	0.011	0.069	0.149
4		5.86	0.143	0.006	0.006	0.172	0.001	0.003	0.006
5		8.27	1.037	2.804	0.177	0.126	0.021	0.048	0.950
6		14.65	0.307	3.632	0.010	0.454	0.003	0.051	0.090

The first three alloys were produced by high-pressure die casting under industrial conditions. Of these three alloys, alloy I is currently used in connecting rods in compressors and its performance thus serves as the reference. The next three alloys (alloys 4—6) were produced by thixoforming in the laboratory. The cooling slope (CS) casting process [7.8] was employed to produce the non-dendritic feedstock for these alloys (Table 2).

Alloy ingots were melted in an electric resistance furnace set at 750 °C. The melt was then allowed to cool to the pouring temperatures between 585 °C and 640 °C. The CS casting involved pouring the molten alloys over a 50mm wide and 500mm long, inclined steel plate into a permanent mold with a diameter of 30mm and a depth of 150mm (Fig. 1). The cooling plate was adjusted at 60" with respect to the horizontal plane and was cooled by water circulation underneath and the cooling length was fixed at 300 mm for all alloys.

Table(2):- Details regarding the cooling slope casting, reheating and T6 heat treatment Parameters employed for the thixoformed alloys.

Parameters	Alloy 4	Alloy 5	Alloy 6
Pouring Temp.(C°)	644	617	584
Cooling Slope Length (mm)	300	320	305
Reheating Temp. (C°)	587	569	573
Reheating Time (min)	6	6	6
Solution Temp. (C°/time h)	530/7	507/7	500/7
Ageing Time (C°/time h)	170/4	176/4	175/4

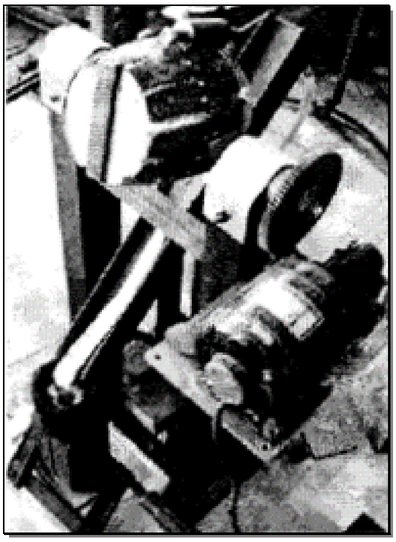

Fig.(1): Show the thixoformed system was used in this work.

The DSC curves covering the solidification range of alloys 4—6 While alloys 4 and 5 were cast with a limited amount of superheat, alloy 6 with a much higher Si content and thus a much higher melting point, was poured below the liquidus temperature, i.e. after crystallization of the primary Si has already started. This practice, recently employed for an A390 alloy [9], avoided a too high pouring temperature yet has produced a very nice as-cast microstructure dominated by _-AI rosettes. The ingots thus obtained were sectioned into 35mm long slugs. A medium frequency induction coil (9.6 kHz, 50 kW) placed right underneath the die was used to heat these slugs in situ, into the semisolid state. Temperature was monitored with a K-type thermocouple inserted in a 3mmdiametcr-hole drilled in the center of the slugs.

Measures were taken to achieve a rapid heating (150°C/min) to prevent undesirable grain growth. The slugs were then soaked at the rehea to allow spheroidization of the grains. The thixoforming operation was carried out with a laboratory press. A pneumatic cylinder was used to provide the forging load (5 tone-f max). The maximum speed of the ram was 500 mm/s and the die was pre-heated to 450 °C. The thermocouple was withdrawn from the sample just before forming. The part produced had inner and outer diameters of 26mm and 36 mm, respectively, and an undercut solid section 26mm in diameter. The HPDC parts were of the same shape and size .The HPDC and thixoformed ('IT) parts thus produced were machined precisely into wear ring test samples. A second set of the thixoformed samples were submitted to the T6 heat treatment before machining (Table 2). T6 heat treatment of the HPDC samples has led to extensive blistering and was thus not appropriate for wear tests. A modified block on ring test unit was employed to identify the wear properties (HPDC) and TF alloys. The conditions, summarized in (Table 3) represent the conditions the connecting rods face in service. The counterforce block material was a heat treated DIN I00Cr6 steel, the common wrist pin material in compressors. The lest chamber was continuously purged with a R600a refrigerant gas. Experiments were conducted with a contact pressure of 277MPa under semi-submerged conditions in a mineral oil lubricant (0.007 Pa s viscosities at 40 °C) at 75 °C. Each test lasted 210 min with an oscillation frequency set at 1.6 Hz. Speed, load, temperature, lubrication conditions were all kept constant in every test. Extent of wear in the ring samples was estimated from weight loss measurements. The samples were cleaned ultrasonically in trichloroethylene before and after each test. An analytic balance with an accuracy of 0.1 mg was used to measure the mass of the samples before and after each test.

Table (3): Wear Test Parameter.

Block Material (counter face)	100 Cr6 Steel
Load (N)	370
Contact Pressure (MPa)	300
Sliding Distance (m)	350
Rotation Speed (r.p.m)	200
Frequency (Hz)	1.7
Time (min)	220
Pendulum Motion Angle (deg)	60
Lubrication	Mineral Oil
Temperature (C°)	75
Continuous Purging of R600a into the Chamber	

3. RESULTS AND DISCUSSION

The microstructural features of the (HPDC) alloys in the die cast state are illustrated in Fig. (6). While Si was shown by XRD to be the dominant phase in all alloys, metallographic analysis provided evidence also for some ternary and quaternary intermetallic phases, the volume fraction of which were apparently too small to generate Bragg reflections. Of the three HPDC alloys, the near-eutectic alloy I exhibit equiaxed _AI cells dispersed in a eutectic matrix (Fig. 6a). Some of these cells are rather coarse and the eutectic Si is almost invariably of the needle variety. Alloys 2 and 3, on the other hand, reveal a uniform dispersion of primary Si particles in an Al-Si eutectic matrix, typical of hypereutectic alloys. Primary Si particles are polygonal and are slightly coarser in the latter, due to the higher Si content of this alloy (Fig. 6b& c). A common feature of the HPDC alloys appears to be a very fine matrix structure owing to the high solidification rates that prevail in this process and occasional micro porosities, often encountered in HPDC aluminum alloys, originating from precipitated hydrogen gas. The microstructural features of the TF alloys (alloys 4 - 6) are typical of semi-solid processing with predominantly _AI globules and Si particles sitting in between (Fig. 7). Aluminum rosettes which have formed upon CS casting were found to undergo substantial spherodization and coarsening during soaking in the semi-solid temperature range (Fig. 8), producing a matrix structure which is relatively coarser than that observed.

In the (HPDC) counterparts. Nevertheless, with an average globule size in the neighborhood of 50 _m and with no evidence of intraglobular liquid, the thixoformed microstructures in the present work show similar features to those previously reported for similar Al-Si alloys (3. 4. 10). The hypoeutectic alloy 4 reveals primary _-AI globules in an Al-Si eutectic matrix while alloy 5 contains, in addition to Si needles, Fe- and Fe/Cu-based intermetallic particles between _-AI globules. The microstructure of the hypereutectic alloy 6 is quite similar to those of alloy 5, but additionally contains primary Si particles between _-AI globules which would not be expected under equilibrium conditions. The T6 heat treatment had a remarkable impact on eutectic Si with little effect, if any, on the _-AI globules (Fig. 9), and without degrading the surface quality in contrast to the HPDC alloys which suffered from extensive blistering (ll) The eutectic Si needles tended to spheroidize in all thixoformed alloys during solutionizing. Nearly perfect spheroidization of the Si needles, which have survived the semi-solid heating cycle, at the relatively lower solutionizing temperature, is believed to be due to the much longer duration of the solution heat treatment. The remaining needle-like particles in T6 treated alloy 5 are find Fe/Cu-based intermetallics which, unlike the Si particles, resisted spheroidization during the solution treatment (Fig. 9b). In addition to changes in the eutectic Si morphology, similar in nature to the above, the primary Si particles in alloy 6 seem to have coarsened slightly upon T6 treatment (Fig.9c). The wear test results are summarized in Table 4, in units of specific wear rate (worn volume per unit sliding distance per unit load) along with the hardness values for the alloys tested in the present work. The wear rates arc substantial and suggest a state of severe wear as one would expect under the test conditions listed in Table (3). Of the six alloys tested under service-like conditions, alloys 2, 3 and 6 performed better than alloy 1, currently used as the connecting rod material in compressors. It is thus fair to conclude that hypereutectic alloys whether produced by high pressure die casting or by thixoforming. Perform better than the near-eutectic and hypoeutectic alloys under the severe wear conditions encountered in compressors. So, replacing the current alloy with a high-Cu, hypereutectic Al-Si alloy, such as A390, offers a twofold increase in wear resistance and would appear to be favorable. The specific wear rates arc shown in graphic form in Fig. (10). Of the three alloys produced with HPDC, alloy 3 with the highest Si content is the most wear-resistant. The favorable effect of Si on wear resistance of Al-Si alloys is evident from a ranking of the three HPDC alloys in respect of their Si contents. The effect of Si on wear properties has been a subject of great controversy over the years (12-25) However, the present work shows convincingly that the wear resistance improves with increasing Si, in agreement with the majority of the recently published work (12, 15, 19). While Si is singled out with its impact on wear properties, other alloying elements are also expected to have an impact on wear properties (26-30). For instance, nearly a twofold decrease in wear rate in alloy 3 with respect to alloy 2 cannot be accounted for by the modest increase in the Si content of the former. Cu apparently plays a critical role and is credited, at least in part, for the superior wear performance of alloy 3. The beneficial effect of Cu on wear performance has been reported by other investigators as well (29, 30) This account of the wear properties in terms of alloy chemistry holds true also for the thixoformed alloys. '1 he wear rates decrease with increasing Si in thixoformed alloys as well.

Alloy 6, with the highest Si and Cu, is once again the most wear resistant among the three alloys produced with thixoforming. This result is in contradiction with that of Ward el al. (6)hat reported a decrease in wear resistance in thixoformed alloys with increasing Si and blamed the difficulty of thixoforming high Si alloys for the poor wear properties. The wear properties of the three HPDC alloys can be accounted for by their microstructural features reasonably well. Lack of primary Si particles and a rather heterogeneous matrix structure is claimed to be responsible for the relatively poor performance of alloy 1 while a uniform dispersion of fine primary Si particles is credited for the superior performance of alloys 2 and 3. Likewise, of the three TF alloys, the superior wear performance of alloy 6 is linked with relatively smaller _-Al globules and a uniform dispersion of fine primary Si particles in between. Such features have been reported to improve the wear properties of Al-Si alloys (17, 27, 31).

Plotting the specific wear rates against hardness for as-cast samples gives a linear relationship with a good correlation (Fig. 11) suggesting that the wear rate decreases with increasing hardness as previously reported (27) .One can see from Fig. (11) that the scatter for HPDC samples is much larger than that for TF samples implying that the wear performance is more predictable and reliable in the latter. This seems to be the major benefit of thixoforming and is possibly accounted for by a more sound part with fewer defects thanks to a higher integrity casting process. It is interesting to note that the substantial hardening produced by the T6 heat treatment did not translate into a sizable improvement in wear resistance of the thixoformed alloys. The specific wear rates for heat treated TF alloys were only slightly lower with respect to those measured in the as-thixofomed state and was even higher in the case of the hypereutectic alloy 6. The modest improvement in wear properties of alloys 4 and 5 may be linked with the modification of the eutectic Si phase upon heat treatment. A uniform distribution of rounded Si particles is certainly good for wear performance (17, 27, 31), The higher hardness of alloys 4 and 5 in the heat-treated state can also be credited (27, 31). These accounts fail, however, to explain why the hypereutectic TF alloy 6 wears more after it was heat treated to the T6 temper, in spite of a substantial increase in its hardness. Coarsening of the primary Si particles may be responsible, at least in part, for the inferior wear properties in this alloy after the heat treatment. While heat treatment is reported to affect the wear resistance of Al-Si alloys, often in a favorable way (16. 26-28). No systematic effect of heat treatment was found on the wear properties of thixoformed alloys in a recent study (6) .further research is needed to understand the inferior wear performance of the heat-treated hypereutectic alloy. Processing of Al-Si alloys is well established to impact their wear properties through its effect on Si particle characteristics (6, 16, 31) .Arriving at sound conclusions regarding the effect of production route on the wear performance is not an easy task in the present case as the chemical compositions of the HPDC and TF alloys are markedly different. Nevertheless, alloys from the two groups with similar wear rates were analyzed for their compositions to identify if thixoforming had any beneficial effect on the wear performance of Al-Si alloys. The wear rates of alloys 1 and 5. Produced by high-pressure die casting and thixoforming, respectively, are nearly equal in spite of a higher Si content in the former. The lower Si content of alloy 5 seems to have been compensated for by the favorable microstructural features imparted to this alloy by the thixoforming processing route.

The performance of alloy 6, which is almost equal to that of alloy 2 at a much lower Si content, is also taken as an encouraging sign for the thixoforming route. It is thus concluded that TF alloys are promising materials for applications requiring wear resistance. Similar results were reported in favor of the TF Al-Si alloys (6, 16).

4. CONCLUSIONS

Hypereutectic Al-Si casting alloys wear less than the near eutectic and hypoeutectic alloys under severe wear conditions encountered in compressors, confirming the impact of Si on wear resistance. Cualso improves near properties. The TF alloys wear at comparable rates with HPDC alloys at lower Si levels, implying that the lower Si content of the former is compensated for by the thixoforming processing route. Better wear test performances are almost invariably linked with a uniform distribution of fine primary Si particles. It is thus concluded that hypereutectic compositions, a favorable Si dispersion and thixoforming as the production route are all good for a superior wear performance. The substantial hardening produced by the T6 heat treatment, however, did not translate into a sizable improvement in wear resistance of the TF alloys.

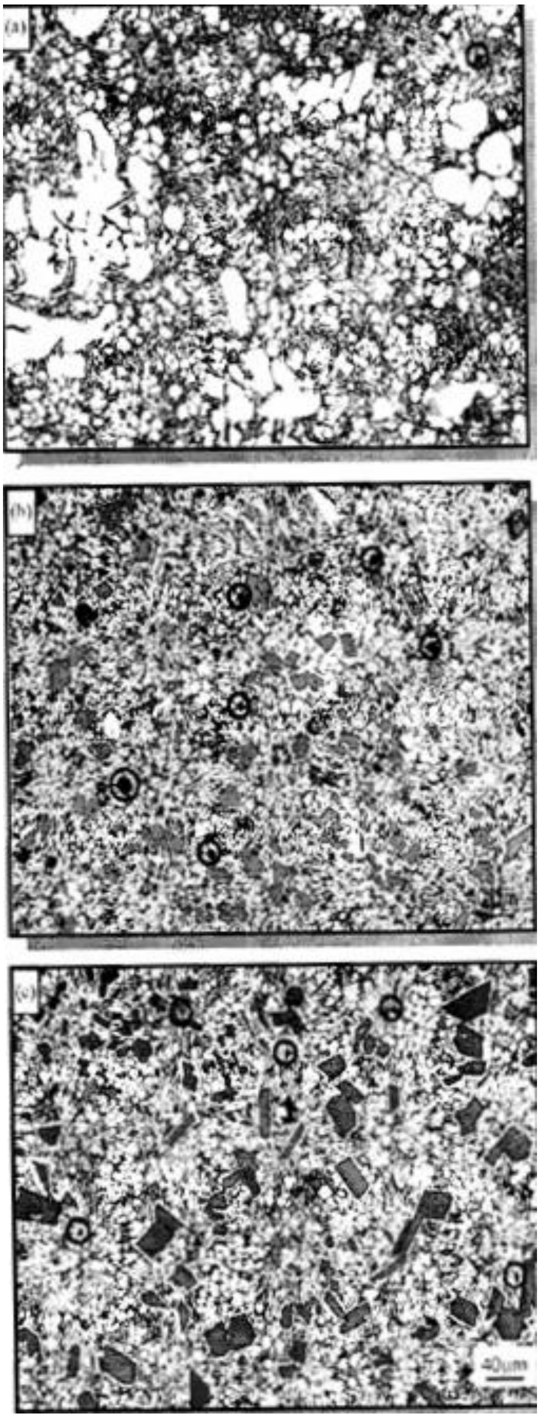

Fig.(2): Microstructures (a-c) of high-pressure die cast Alloys(Alloys 1-3).

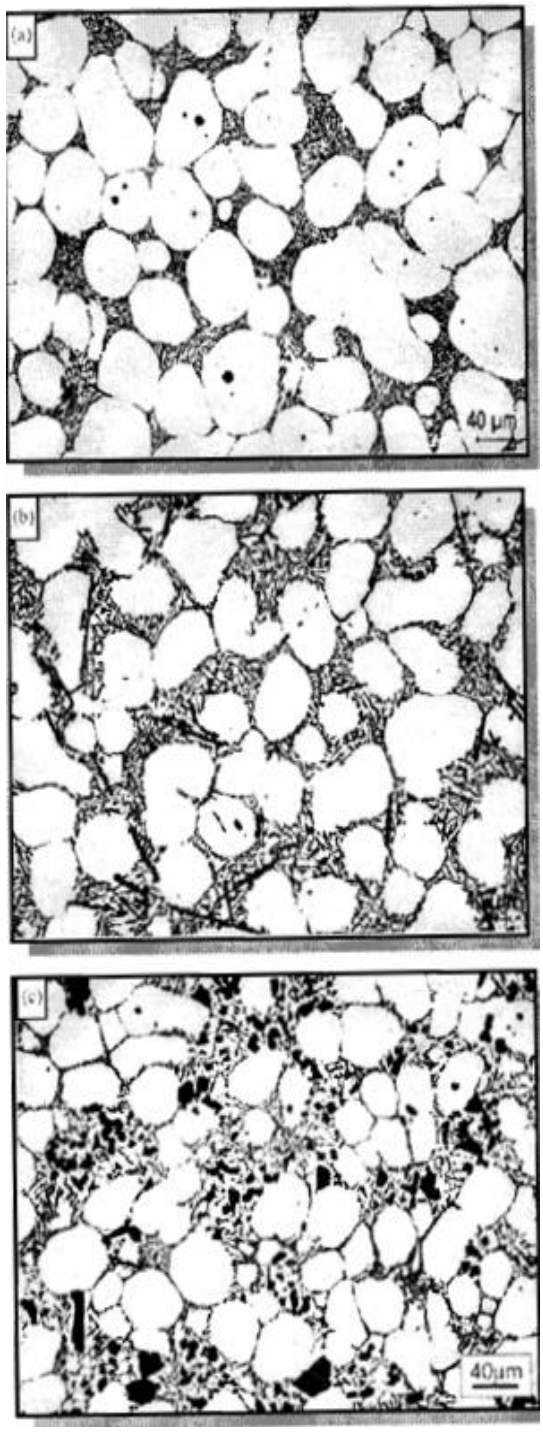

Fig.(3): Microstructure (a-c) of thixoformed Alloys (Alloys 4-6).

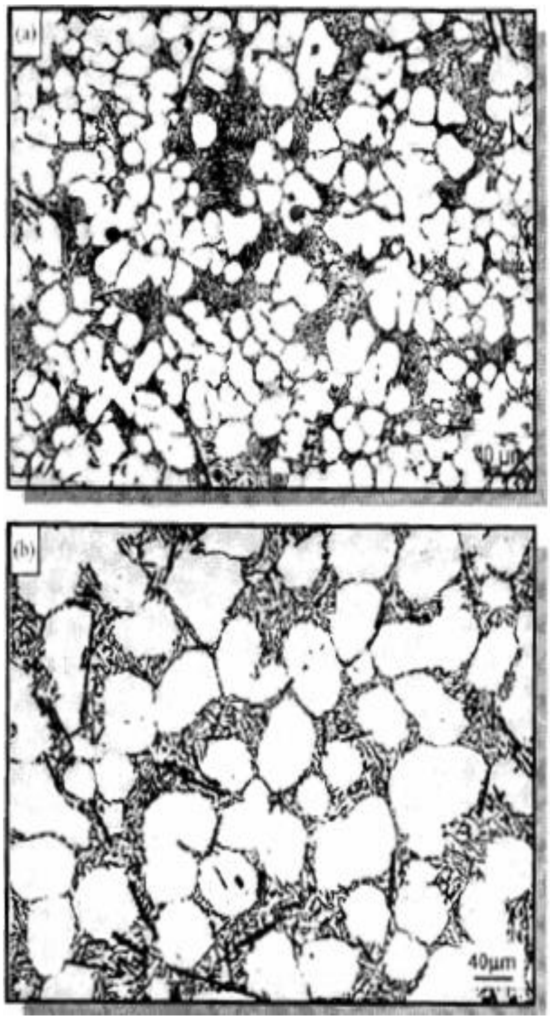

Fig.(4): Microstructure of Alloy 5 (a) after cooling slope casting and (b) after reheating in the semi-solid temperature range.

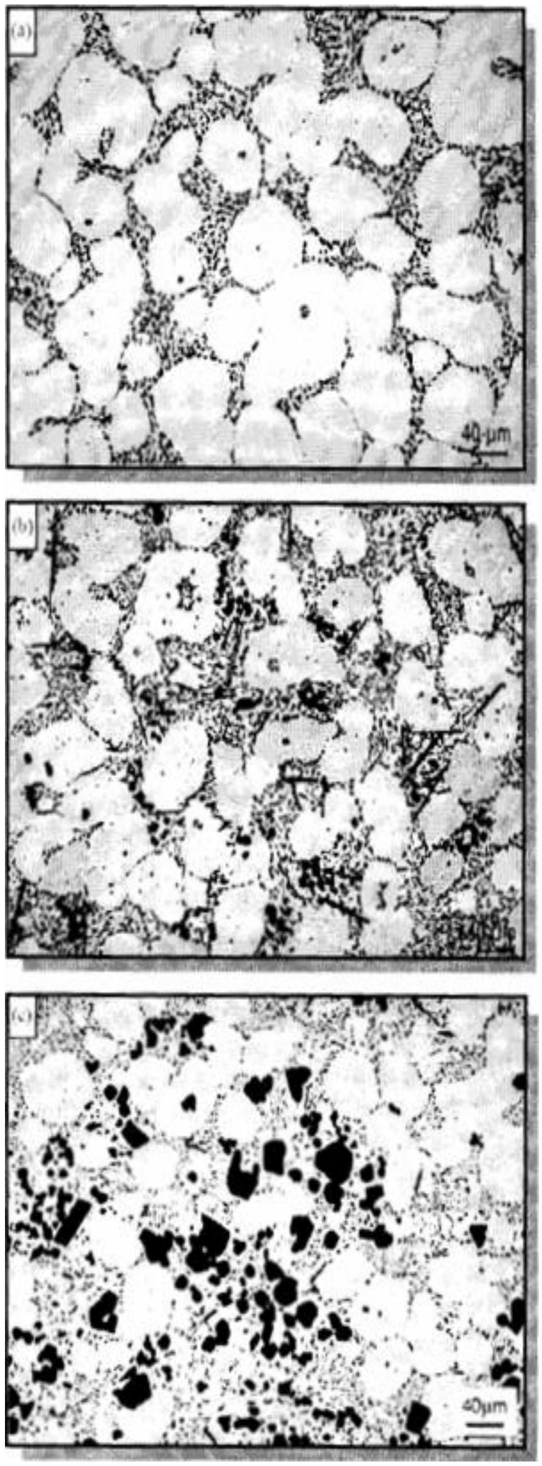

Fig.(5): Microstructure (a-c) of heat treated thixoformed Alloys(Alloy 4-6).

Table(4): The wear rate and the hardness results.

Alloy	K(x10^{-5} mm^3/Nm)	Hardness (HB)
1	5.4	94
2	2.61	87
3	1.74	100
4	10.3	54
5	5.2	84
6	2.73	96
7	7.8	76
8	3.57	124
9	4.66	147
HPDC, high-pressure die cast; TF, thixoformed		

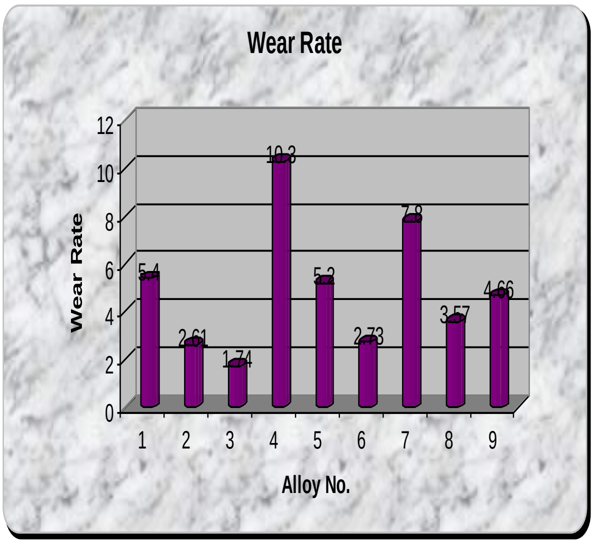

Fig.(10): Wear rate value for alloy no.

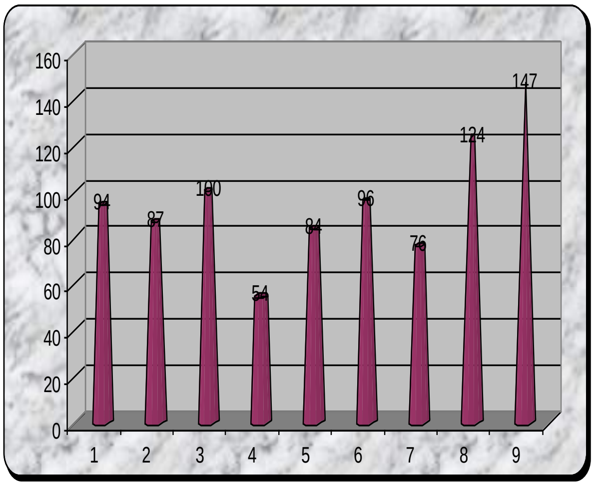

Fig.(11): Hardness value for alloy no.

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تحضير سبائك ثايكسوفورميد الألمنيوم بواسطة سباكة الضغط العالي ودراسة خواص البلى لها

عقيل علي كاظم

مدرس مساعد

قسم هندسة الانتاج والمعادن– الجامعة التكنولوجية

الخلاصة

تعتبر سبيكة الألمنيوم–سيليكون المسبوكة من السبائك ذات التطبيقات الواسعة وخصوصاً في أنظمة الضاغطات. ولهذا السبب تم إنتاج العديد من سبائك Al-Si بطرق الضغط أو العصر أو بالطريقة الهلامية (العجينة) ودراسة تأثير البلى على هذه السبيكة ومعرفة مدى تأثير السيليكون على مقاومة البلى وكذلك معرفة مدى تحسين مقاومة البلى من خلال طريقة التصنيع بالحالة الهلامية، ومن خلال هذا البحث تم التوصل إلى زيادة البلى عن طريق التصنيع بالحالة الهلامية

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