Studying the dry sliding wear behavior of Al-4%Cu/ SiC Metal Matrix Composite with heat treatment

Ali Ismail salih[1], Mohammed ghazi Hammed[2], Ahmed Ibid Ibrahim[1]

[1] *Department of Physics, College of science, Kirkuk University, Kirkuk , Iraq*

[2] *Department of Physics, College of science, Al-Anbar University, Anbar , Iraq*

(**Received:** 2 / 10 / 2011 ---- **Accepted:** 6 / 2 / 2012)

Abstract:

In This study metal matrix composite (MMCs) was produced by using aluminum as base metal matrix reinforced with the SiC particulates using conventional casting technique, macro structural studies showed that uniform distribution of SiC particulates. The density of MMCs decreased with the increase in SiC wt%. The Hardness of MMCs increased with the increase in SiC wt%, composites exhibit a significant acceleration in kinetics of preciptation in compare with the unreinforced matrix alloy. A pin on disc wear testing machine was used to evaluated the wear loss of composites. The results showed that wear rates of composites are lower than of the matrix alloy and further decrease with increase in SiC particulate content.

Keywords: Aluminum alloy, MMCs, SiC, wear, precipitation hardening

1. Introduction:

Metal matrix composites (MMCs) represent a new generation of engineering materials in which a strong ceramic reinforcement material like SiC(1-20), Al_2O_3(3,5,21,22,23), carbon fiber(20), silca(24) and graphate(25), these reinforcement material is incorporated into a metal matrix to improve its properties including specific strength and specific stiffness (4,8, 12, 13,19), wear resistance(1, 2, 3, 5, 18, 21, 25), excellent corrosion resistance(1, 22), and high elastic modulus[12, 24]. MMCs combine metallic properties of matrix alloys (high ductility and toughness) with ceramic properties of reinforcements (high strength and modulus), leading to greater strength in shear and compression and higher service temperature capabilities(2, 5,10,11, 12, 13,16, 24). During last decade, the improved properties of MMCs are being used extensively for high performance applications in aircraft engines, in automotive industry(2) and electrical application(12). Silicon carbide (SiC) reinforcements in form of fibers(6, 12, 13, 14, 15, 17, 23) or particles(1, 2, 3, 4, 5, 7, 8, 9,10,11, 16,18,19,20) are the most common reinforcements in MMCs and their additions to aluminum alloys have been the subject of a considerable amount of research. The reinforced composites are commonly produced by different techniques like; stir cast (1, 11, 18), squeeze (4), deposition(9) pressure infiltration(22, 23), and powder metallurgy (2, 12, 19). The purpose of the present work is to produce the SiC particle-reinforced metal matrix composites by cast. The SiC wt% was varied to showed their effect on the mechanical and structural properties of composites are investigated. Moreover, the effect of SiC particle content on the density and trabological properties are studied and correlated to microstructure properties.

2. Experimental Procedure:

SiC particulate reinforced composites were produced by casting. The matrix an alloy of the composite was prepared, first by melting pure aluminum in an electrical furnace and then 4% Cu in weight was added to the melt. The matrix alloys were reinforced by the same SiC particles size which was average 53□m. All the melting was carried out in an alumina crucible in the electrical furnace. The furnace temperature was heated to 730^{o}C. Before mixing the SiC particles were preheated at 700°*C* for 1 hour to degazing and to prepare its surface to make good wettablity with aluminum alloy. The furnace temperature was first raised above the liquids to melt the alloy completely and was then cooled down just below the liquidus to keep the slurry in a semi-solid state. At this stage the preheated SiC particles were added and mixed manually. Manual mixing was used because it was very difficult to mix using automatic device when the alloy was in a semi-solid state. After sufficient manual mixing was done, the composite slurry was re-heated to a fully liquid state, and then automatic mechanical mixing was carried out for about 20 minutes at an average stirring rate of 200 *rpm.* In the final mixing processes, the furnace temperature was controlled to be within730°C. The composite and the matrix alloys were poured in a preheated permanent steel mould. The metal matrix composites produced were exposed to solutionising and age hardening heat treatment. The solutionising treatment was applied for 20 hours at 500 ºC, and age hardening was done for 16 hours at175 ºC.

Density measurements were carried out on the base metal and reinforced samples. Density measurements were carried out using Archimedes's principle. The buoyant force on a submerged object is equal to the weight of the fluid displaced. This principle is useful for determining the volume and therefore the density of any shaped object, by measuring its mass in air and its effective mass when submerged in water (density = 1 g/cm^3). This effective mass under water will be its actual mass minus the mass of the fluid displaced. The difference between the real and effective masses therefore gives the mass of the displaced water and allows the volume of the object to be calculated. Mass divided by the volume thus determined gives a measure of the average density of the object.

Bulk hardness (Brinell hardness) measurements were carried out on the base metal and composite samples. The hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness. Also it's useful to determine the effect of heat treatments which are used for age hardening to get good precipitation hardening. It's determined with 10mm ball and under load of 500N exerted for 30 seconds.

The fact is that tribological properties are the one that define possible application of material far more than their mechanical properties, since they are in better correlation with behavior in practice. The wear specimens were tested under dry (unlubricated) conditions in accordance with ASTM-G99 standards using a pin-on-disc sliding wear testing machine. The apparatus consists of a steel disc of hardness 320Hv and diameter 250 mm, which is the counterface on which the test specimen slides. The arrangement were made to hold a specimen and also for application of the load on the specimen. The test sample was clamped in the specimen holder and held against the rotating steel disc. In present investigation, loads of 4.9N, 9.8N and 14.7 N was used .The speed was varied from 100, 200 and 300m/min. the sliding distance used was 3000m. The composite sample was machined on lathe to prepare Φ10mm × 25mm rod samples. One surface of each sample was ground with 240, 400, 500, 800, 1200 grit abrasive paper, cooled with water, then polished with diamond pastes of 3μm, 1μm, 0.25μm. Then samples were degreased by ethanol and dried was ground with 400,500 grit silicon carbide papers. The disc rotational speed was 500 r.p.m that means a linear velocity of 100, 200, and 300 m.min-1 which was calculated using the formula ($V=2\pi \times r \times n$). The specimen was weighed before and after the tests using an electronic balance accurate to 0.0001 g. The dry sliding wear loss was computed using the weight loss (ΔW) g of the pin before and after the experiments. Wear rates were calculated by the weight loss measurement of the sample. The formula used to convert the weight loss into wear rate is (ΔW / linear distance) mg.cm-1. The surfaces of the worn specimens were cleaned thoroughly to remove the loose wear debris and then observed using a photo microscope. Since the hardness of the counterface (steel disc) was far higher than that of the specimens and its wear volume was very small therefore there effect was neglect.

Metallographic samples were sectioned from the cast bars and were prepared. Microstructures were examined on the samples under the optical microscope.

3. Results and discussion:

The density of the composites was measured. Fig. 1 shows the effect of SiC content on the value of density was decreased. Its expected result because with increasing the weight percentage of SiC, the porosity of the composites increases. This may be due to the increase of stirring time required to disperse the SiC which increases the air bubbles entering the slurry.

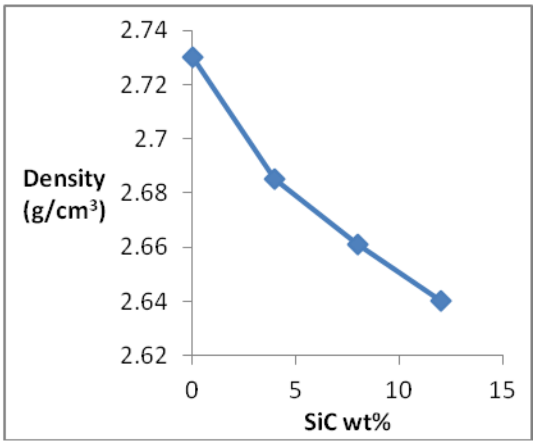
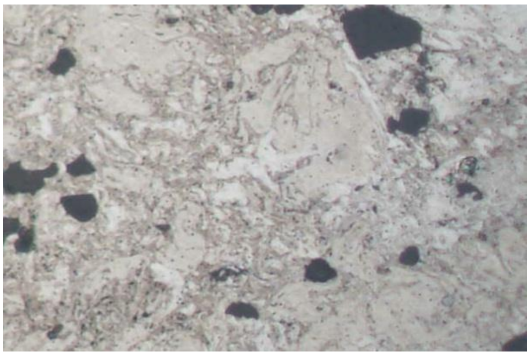
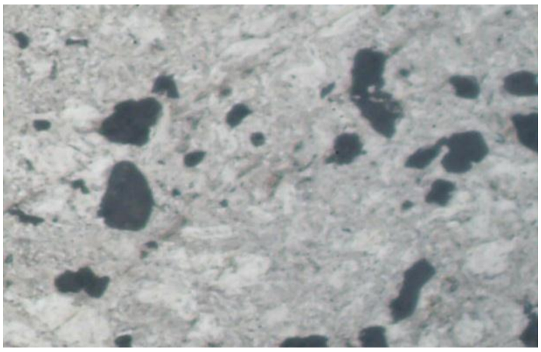


Figure (1) the SiC wt% as a function to the density of the reinforcement alloys.

Fig(2) and Fig(3) show microstructure of MMCs with SiC particles distribution in the matrix. Microstructure shows that there is no void or discontinuities and reasonable uniform distribution of SiC particulates.



Figure(2) Microstructure of cast composites Al-4%Cu/4% SiC showing homogeneous SiC distribution , 540X



Figure(3) Microstructure of cast composites Al-4%Cu/8% SiC showing homogeneous SiC distribution , 540X

Figure(4) shows the age hardening curves for the matrix alloy and reinforcement alloys. It was found that, the addition of SiC particle to the matrix alloy reduces the time required to reach the peak hardness as compared to the matrix alloy (4-6) hours for composites and (9-10) hours for matrix alloy. Also, increasing the weight % of SiCp reduces the time required to reach the peak hardness. It was found that addition of SiC particle to the matrix alloy increased the hardness and this increase was maintained during the different stages of artificial aging. The highest hardness value of 102 HB was observed for the reinforcement alloys having 12% wt SiC particle. The accelerated aging behaviour observed in the present investigation may be a result of an increased dislocation density in the vicinity of SiC particle, which is due to a large difference in the coefficient of thermal expansion between SiC particle and the matrix. The higher dislocation density can both aid the diffusion of solute atoms and serve as nucleation sites, thereby leading to a more rapid precipitation process.

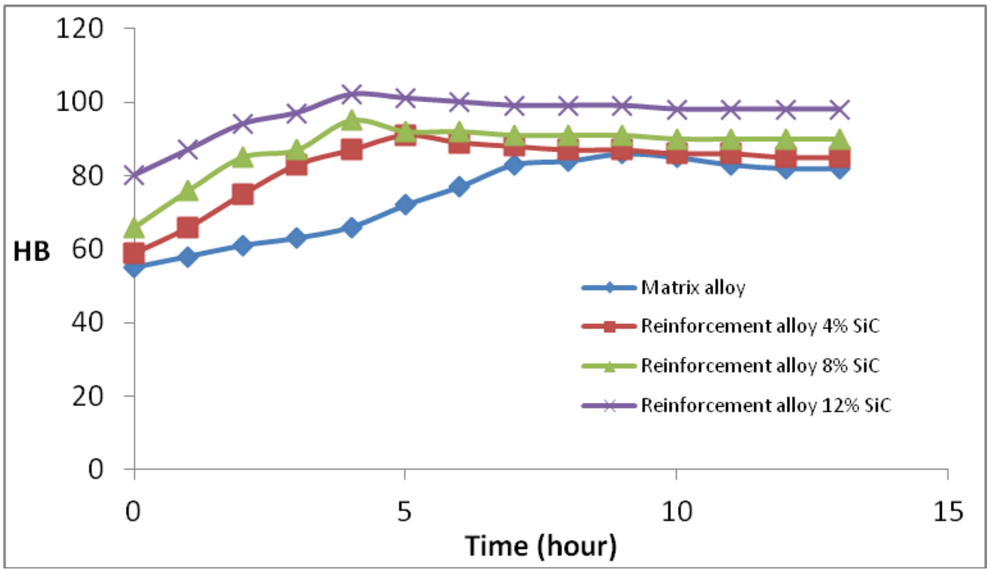


Figure (4) the aging time as a function to the hardness of matrix alloy and reinforced alloys

From the figure (4) in all cases after a different time the hardness reached the maximum value but when the time was increased the hardness decreased because the distribution of copper atoms changes with time from random to the disk like planar aggregates (GP) zones, which form on particular crystallographic planes of the aluminum matrix. At higher temperatures, transition forms of approximate composition Al_2Cu develop and further increase strength. In the highest strength condition, both the θ'' and θ' transition precipitates may be present. When time and temperature are increased sufficiently to form high proportions of the equilibrium θ, the alloy softens and is said to be "over aged."

The GP zones are of the size range of tens of angstroms in diameter. They are essentially distorted regions of the matrix lattice, rather than discrete particles of a new phase having a different lattice. The equilibrium solid solubility of copper in aluminum increases as temperature increases. When the alloy is held at such temperatures for sufficient time to permit needed diffusion, the copper will be taken completely into solid solution. At temperatures below the solvus, the equilibrium state consists of two solid phases: solid solution, α, plus an intermetallic-compound phase θ(Al_2Cu). When such an alloy is converted to all solid solution by holding above the solvus temperature and then the temperature is decreased to below the solvus, the solid solution becomes supersaturated and the alloy seeks the equilibrium two-phase condition; the second phase tends to form by solid-state precipitation.

Super-Saturated Solid solution □GP zones □θ'' □□θ' □θ(Al_2Cu)

The results of wear studies on SiC particulate reinforced Al-Cu/SiC MMCs is shown in figure (5) and figure(6) . The results revealed that the losing in the weight would decrease as the SiC content were increased. In all the test results it’s evident that the resistance to wear increases with increasing SiC wt% also the amount of wear increases with increasing normal load the sliding wear behavior of MMCs for various normal loads is shown in the figure (5), with increasing normal load MMCs underwent a transition from mild to severe wear. Variation in sliding velocity was achieved to study the wear behavior for the various sliding velocities. Figure (6) shows that the amount of wear increased with increasing sliding velocity especially for matrix alloy, it was changed from mild to severe wear with increasing the velocity which is expectable.

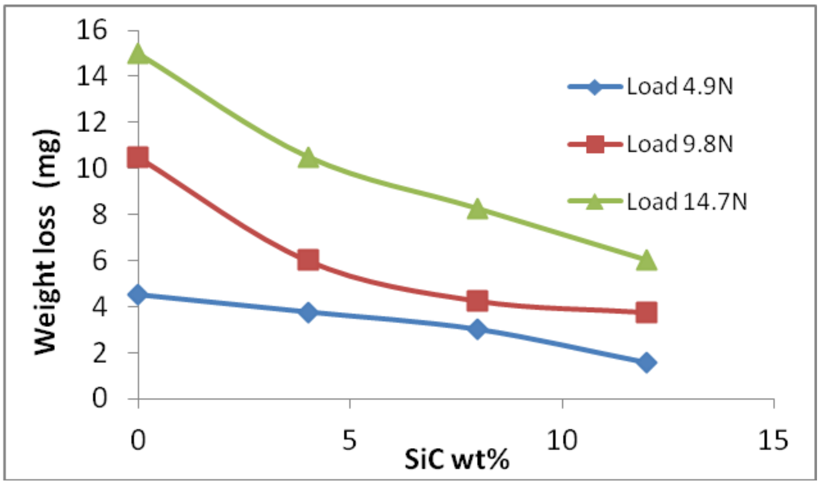


Figure (5) Weight loss of MMCs samples as a function of wt% of SiC with using different load (4.9, 9.8, 14.7) N and sliding distance 3000m for 30 minute.

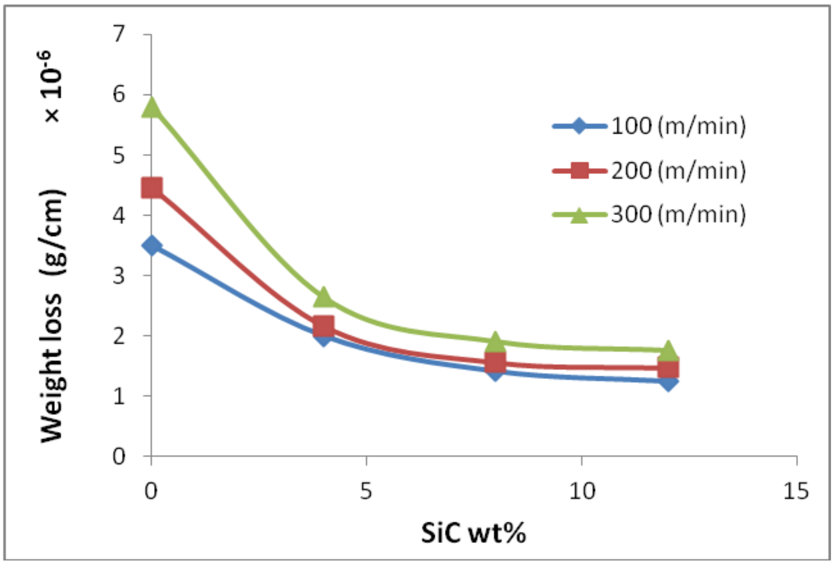
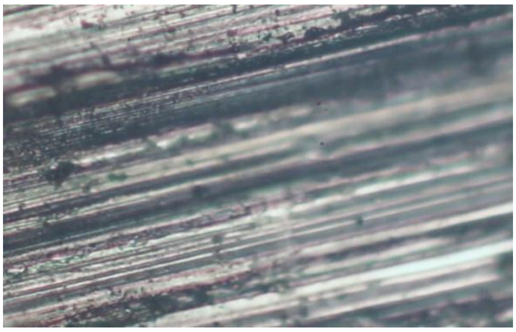


Figure (6) Wear rate of MMCs samples as a function with wt% of SiC at sliding speed (100, 200, and 300) m/min with 9.8 N loads for 30 minute.

Figure (7) showed number of grooves, mostly parallel to the sliding direction is evident on all the worn pins. Grooving appears more severe at the higher loads of 14.7N. Grooves were less severe for lower loads lower speeds, the hard asperities of steel counterface or hard reinforced particles in between the contacting surfaces, plough or cut into the pin causing wear by the removal of small fragments materials. As the load increses further cracking occurs and cumbination of abrasion, delamition and adhesion wear observed.



Figure(7) The wear surface of Al-4%Cu/4%SiC composite at speed of 100m/min and load 9.8 N after runningfor a distance of 3000m.

4. Conclusion:

1. Composites exhibit a significant acceleration in kinetics of preciptation in compare with the unreinforced matrix alloy. This acceleration is attributed to adecrease in the incubation time required to achieve the peak hardness.

2. The addition of SiC to Al-4%Cu alloy increases the hardness of reinfocement alloy with increasing SiC content.
3. The SiC particle reinforced exhibted reduced dry sliding wear loss than the unreinforced alloy. The wear loss decreased with increasing in SiC content.
4. The dry sliding wear loss of composites as well as the matrix alloy increased with the increase in the liner speed of the movement and load applied.
5. The microstructure of the worn surface revealed the large amount of plastic deformation was observed on the surface of the unreinforced aluminum alloy. While Al-4%Cu / SiC renforced alloy. The worn out surfaces are not smooth, and the grooves, scratches and parallel lines were observed.

5. Reference:

1. M. Ramachandra, K. Radhakrishna. Materials Science- Poland, Vol. 24, No. 2/1, (2006) 334-349.
2. H. S. Lee, J. S. Yeo, S. H. Hong, D. J. Yoon, K. H. Na. Journal of Materials processing Technology. 113 (2001) 202-208.
3. E. Bonollo, L. Ceschini', G.L. Garagnani, G. Palombarini, I. Tangerinie and A. Zambon. JOURNAL DE PHYSIQUE IV, Colloque C7, suppltment au Journal de Physique 111. Volume 3, novembre (1993) 1845-1847.
4. YU Xiao-dong, WANG Yang- wei, WANG Fu-chi. Transaction of nonferrous Metals Society of china 17, (2007) 276-279.
5. G. B. Veeresh Kumar, C. S. P. Rao, N. Selvaraj, M. S. Bhagyashekar. Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.1, (2010) 43-55.
6. R. J. Mustafa. Jordan Journal of Mechanical and Industrial Engineering. Vol. 4, No. 2, (ISSN 1995-6665) (2010) 246 - 255.
7. J.T. Lin, D. Bhattacharyya , C. Lane . Wear. 181-183 (1995) 883-888.
8. M. M. Ranjbaran. European Journal of Scientific Research ISSN 1450-216X Vol.41 No.2 (2010) 261-272.
9. V. C. SRIVASTAVA and S. N. OJHA. Bull. Mater. Sci, Vol. 28, No. 2, April (2005) 125–130.
10. N. Chawla and X. Deng. Materials Science and Engineering A 426 (2006) 314–322.
11. A. Chennakesava Reddy and Essa Zitoun . Indian Journal of Science and Technology Vol. 3 No. 12 ISSN: 0974- 6846, Dec (2010)1184-1187.
12. D. Webster . Journal of Mat Trans Vol 13A, August (1982)1511-1519.
13. C. H. Andersson and R. Warren: Part I. J. composite Vol 15. No.1 January (1984) 16-24.
14. C. H. Andersson and R. Warren: Part II" J. composite Vol 15. No.2 January (1984) 101-109.
15. Y.Flom and R.J.Arsenault. Journal of Acta Metal Vol 37 No.9 (1989) 2413-2423.
16. D.J.Lloyd. Journal of composites science and technology Vol 35, (1989) 159-179.
17. R. L. Deuis, C. Subramanian and J. M. Yellup. Composites science and technology , 57, (1997) 415-435.
18. S. Basavarjappa, G. Chandramohan, R. Subramanian, A. Chandrasekar. Material Science-Poland, Vol. 24, No.1, (2006) 357-366
19. J. C. Viala, P. Fortier, J. Bouix. Journal of material science 25 (1990) 1842-1850
20. J. p. Rocher, J. M. Quenisset, R. Naslain. Journal of matrial science letters 4 (1985) 1527-1529.
21. A. Vencl, A. Rac, I. Bobic, Z. Miskovic. Tribology in industry, Volume 28, No. 1&2, (2006) 27-31.
22. L.A. Dobrzański, M. Kremzer, M. Drak. journal of Achievements in Materials and Manufacturing Engineering, VOLUME 30,ISSUE 2, October (2008) 121-127.
23. J. Yang, D. D. Chung. Journal of matrials science, 24, (1989) 3605-3612.
24. A. M. S. Hamouda, S. Sulaiman, T. R. Vijayaram, M. Sayuti, M. H. M. Ahmad. Journal of Achievements in Materials and Manufacturing Engineering, Volume 25 Issue 2, December (2007) 11-16.
25. S. Basavarajappa, G. Chandramohan. ISSN 1392-1320, Materials Science (MEDZIAGOTRA). Vol.11, No.3. (2005)253-257.

دراسة سلوك الانزلاق الجاف للمادة المركبة Al-4%Cu/ SiC والمعاملة حراريا

علي أسماعيل صالح[1] ، محمد غازي حمد[2] ، أحمد عبد أبراهيم[1]

[1]*قسم الفيزياء ، كلية العلوم ، جامعة كركوك ، كركوك ، ألعراق*

[2]*قسم الفيزياء ، كلية العلوم ، جامعة الانبار ، ألأنبار ، ألعراق*

(**تاريخ الاستلام:** 2 / 10 / 2011 ---- **تاريخ القبول:** 6 / 2 / 2012)

الملخص:

في هذه الدراسة تم أستعمال معدن الالمنيوم كمادة أساس وحبيبات كاربيد السلكون كمادة تقوية وذلك بأستخدام تقنياتَ الصب التقليديةِ في انتاج المادة الاساس والمادة المدعمة، أظهرت نتائج الفحص العياني للتركيب بأنّ التوزيعِ الحبيبي لمادة التقوية وهي حبيبات كاربيد السلكون كانت منتظمة أما كثافة المادة المدعمة فقد أنخفضت بزيادةِ نسبة حبيبات كاربيد السلكون المضافة. وبالنسبة للصلادة فهي زادت للمادة المركبة بزيادةِ نسبة حبيبات كاربيد السلكون ألمضافة، وحصل زيادة في سرعة الترسيب للمادة المدعمة بحبيبات كاربيد السلكون بالمقارنةِ مع سبيكةِ المادة الاساس غير المدعمةِ. أستخدمت تقنية الدبّوس على ماكنةِ أختبار البلى والتي تستعمل القرصِ الدوار لمعرفة خسارةِ البلى للمادة الاساس والمادة المدعمة. أظهرت النَتائِجَ بأنّ نِسَبِة خسارة البلى للمادة المدعمة أوطأ مِنْها بالنسبة لسبيكةِ المادة المتراكبة الاساس ويزداد النقصانَ بزيادةِ المحتوى من حبيبات كاربيد السلكون.

الكلمات المفتاح: سبائك الالمنيوم، المواد المتراكبة، كاربيد السلكون، البلى، التصليد بالترسيبس.