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by

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Behavior of as cast and hot rolled composites at room and elevated temperatures

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The present work investigates the effect of hot rolling on the agglomeration of particles, mechanical properties and tribological behaviors of particulate composites. Experimental work was carried out on aluminum alloy A 413matrix reinforced with different volume fractions of SiC particulate prepared by vortex casting technique, both in the as-cast in the hot rolled conditions. Tensile, hardness and creep tests were conducted on as cast and hot rolled specimens at room and elevated temperatures. The impact toughness was tested for specimens of different volume fractions at room temperature. The wear rate at room temperature of as cast and hot rolled matrix and composite specimens were investigated at different applied loads and sliding speeds. The obtained results revealed that subsequent hot rolling deformation reduces the agglomeration of ceramic particles and improves the mechanical and tribological properties as compared to the as cast composites. The increases of particle volume fraction to 12 vol. % improve mechanical properties and wear resistance. Creep test results indicate that, the rupture time is inversely proportional to particle volume fraction for as cast composite specimens, whereas it reveals direct proportionality in the case of specimens fabricated by vortex followed by hot rolling. Fractography revealed that, composite specimens failed by voids initing at the particle-matrix interface. The impact energy increases with increasing volume fraction in the case of hot rolled composites, whereas the inverse was the case for as cast composite specimens.

المواد المركبة لها أهمية كبيرة في التطبيقات الهندسية ومن أهم الطرق المستخدمة في تحضير المواد المركبة في طريقة الخلط مع تقليب المعدن المنصهر ولكن لهذه الطريقة بعض العيوب أهمها هو عدم انتظام توزيع حبيبات السيراميك مع وجود بعض الفراغات داخل المادة المركبة. لذلك يهدف هذا البحث إلى دراسة إمكانية التخلص من هذه العيوب باستخدام طريقة الدرفلة على الساخن مع مقارنة الخواص الميكانيكية عند درجة حرارة الغرفة وكذلك عند درجات حرارة مختلفة وذلك للعينات المعدة بطريقة التقليب والعينات المعدة بطرقة التقليب مع الدرفلة على الساخن وقد امتد البحث إلى مقارنة الصلادة والتآكل في كلاً الحالتين.وقد تم عرض النتائج ومناقشتها واستخلاص أهم التوصيات التي تساعد في هذا المجال.

Keywords: MMC, Hot rolling, Mechanical properties, Tribological properties, Creep

1. Introduction

A wide variety of fabrication techniques have been explored for metal matrix composites. These include liquid phase methods, deposition of matrix from a semi-solid or vapor phase, and solid-state methods or techniques. Liquid phase processing has attractive economic aspects. Chopped fibers, porous ceramic compacts and particulates have been incorporated into molten matrix alloys. In some cases, pressure assistance has been used to infiltrate the reinforcement with molten matrix. These methods result in microstructures dictated by the solidification of the molten metal [1-4].

A composite prepared by vortex technique suffers large content of porosity and inhomogenity due to agglomeration of particles [3, 4]. Squeeze casting has proved to be efficient in overcoming the above mentioned shortcoming. However the squeeze casting technique has the disadvantage of expensive die and technical complexity.

The importance of Metal Matrix Composites (MMCs) has increased in the last decades because of their superior mechanical and physical properties. Using ceramic particulates as reinforcement, combined with liquid metal techniques for processing, result in producing relatively cheaper composites as compared to complicated processing techniques [1]. Although considerable progress

has been made in researches on MMCs because of high strength, high specific stiffness, and low thermal expansion coefficient etc., studies on forming behaviors of composite at high temperature were not so satisfactory [1,3]. Metal matrix composites offer themselves as strong candidates for a variety of engineering applications especially in aerospace and automotive sectors. Metal matrix composites reinforced with discontinuous particulates have a decisive advantage in cost and versatility over fiber reinforced composites [5, 6]. The property profiles of such composites fall somewhere between the dispersion strengthened and fiber strengthened extremes. The high cost of equipment, and complexity of solid state pressures have led to the development of relatively inexpensive processes like the liquid metallurgy technique [7]. By adopting conventional processing, the technique enables the benefit from the ease of processing while maintaining low cost.

Composite fabrication technique is an important consideration. For a given set of constituents, the fundamental link between properties and cost is determined by fabrication method. Processing, in general, is concerned with introduction of reinforcement into the matrix with a uniform distribution [1,8]. A major hurdle is the achievement of proper bonding between the matrix and the reinforcement in order to attain good load transfer between phases. Not all combinations of reinforcement and matrix are compatible and many cannot be processed into commercially useful composites. In some composites, the coupling between the reinforcement and the matrix is poor and adhesion promoters are needed. In others excessive interfacial reactivity can lead to a brittle layer around the reinforcement [1,2,3,10].

2. Experimental work

The present work investigates how the particulates are rediculates are redistributed in MMCs due to hot rolling. Hot rolling experiments have been conducted at 560°C on as cast composite ingots to different thickness reduction ranging from 5% to 30%. The experiments revealed 25% is the optimum thickness reduction whick satisfying due to the crakes was appeared after this ratio.

3. Fabrication of composite specimens

The vortex technique was used for fabrication of silicon carbide particulate reinforced aluminum alloy matrix A 413 composites. The chemical compositions of the matrix alloy and reinforcement particulate are shown in tables 1 and 2, respectively. The particles were treated by, impregnating them in a solution containing N+ ions for several hours, and then they were dried. This treatment is essential to introduce the SiCp into the molten matrix. The matrix alloy was cut to small pieces, and then charged to the crucible furnace of 3 kW electric power. When the matrix was melted, it was stirred using mechanical stirrer. The stirrer impeller could be lifted or lowered inside the crucible, and was driven by variable speed motor. The impeller was completely immersed in the molten metal and its axis was parallel to the crucible axis. As soon as a satisfactory vortex was created, The SiC particulates of size 28 um, preheated at 400° C for 2 hours, were gradually added in the vortex.

The time needed for the addition of SiC particulate was varied between 20 and 50 min., according to the volume fraction of SiC particulate. When the addition of SiC particulates was completed, stirring of the mixture was maintained for another 15 min., then the mixture was poured at 720° C into the prepared steel die. During melting operation, borax powder was added into the molten metal in order to clean the metal. After complete solidification, the cast was obtained from the mold, then it is cut and machined to the required specimens shape and dimensions. Groups of the cast were heated to 560° C then they were hot rolled to 75 % of the initial height. A rolling stand of 150 mm rolling mill diameter and 200 mm length drived by 5 kW electric motor through a reduction unit of 1/125 speed ratio was specially designed for this purpose. The rolled ingots were cut to the required specimens shape and dimensions. The as cast and hot rolled specimens were heat treated as follows: solution treated at 530°C for one and a half

Table 1
Composition of matrix alloy A 413 (wt.%)

Alloy	Si	Fe	Cu	Cr	Mn	Mg	Ti	Ni	Zn
A 413	10.8	0.0921	0.0001	0.0001	0.00108	0.239	0.134	0.0004	0.0009

Table 2
Composition of SiC particulates

Constituent	SiC	SiO_2	C	Al_2O_3	Si	Fe_2O_3
Wt.%	98.0	0.75	0.4	0.2	0.6	0.05

hour, water quenched, naturally aged at room temperature for 2 hours and artificially aged at 175°C for 8 hours.

4. Results and discussion

4.1. Microstructure of as-cast metal matrix composite

The results of optical microscope examination of matrix alloy as received and hot rolled were shown in figs. 1-a and 1-b, respectively. fig. 1-a shows the Si present in the form of long and thick fibers, while a small and fine structure of Si was noticed in case of hot rolling as shown in fig. 1-b. The distribution of the reinforcing particulate in the metal matrix composite specimens fabricated by vortex and vortex combined by hot rolling processes were shown in figs. 2-a and 2-b, respectively. The obtained results shown in fig. 2-a for composite specimens fabricated by vortex method, exhibit clusters of reinforcing particulates randomly distributed. Dark areas were observed around reinforcing particulate and in matrix, which indicate prosity positions and bad interface between matrix and particulates. The size of reinforcing clusters represent the agglomeration of reinforcing particulate, where high agglomeration was noticed for specimens of high volume fraction.

The micrographs shown in fig. 2-b indicates the distribution of reinforcing particulate for composite specimens subjected to hot rolling processes. An excellent reinforcing particulate distribution was noticed in specimens fabricated by vortex followed by hot rolling operation as compared to that fabricated by vortex technique. The micrograph indicates no dark spots in matrix or around the reinforcing particulate, with absence of agglomerations.

EX-200

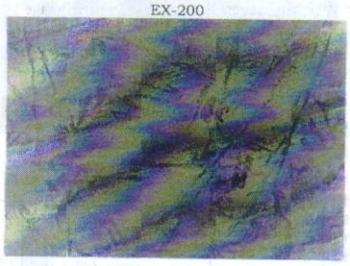


Fig. 1-a. Matrix as received.

X-200

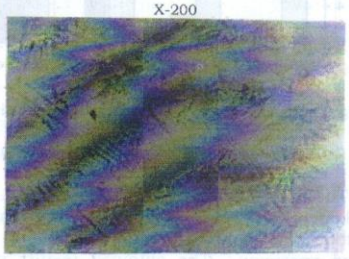


Fig. 1-b. Matrix hot rolled.

X-200

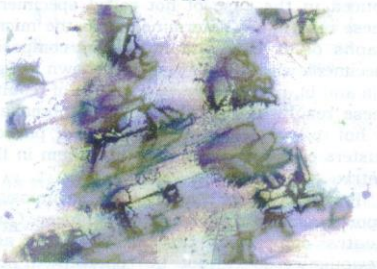


Fig. 2-a. Composite with 20 vol. % as cast.

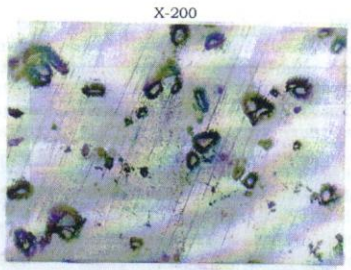


Fig. 2-b. Composite with 20 vol. % hot rolled.

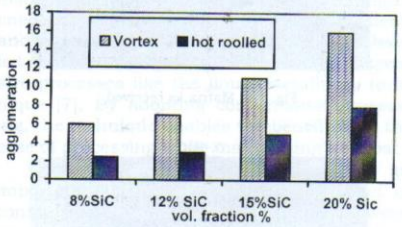


Fig. 3. Agglomeration % vrsus volume fraction of SiC.

4.2. Effect of volume fraction on agglomeration

The results shown in fig. 3 represent the agglomeration percentage versus volume fraction of SiC particulate for as cast and hot rolled specimens. The obtained results indicate that, the increase of volume fraction of reinforcement increase the agglomeration percentage, where a small agglomeration were noticed in the case of hot rolled specimens. These results are determined from the micrographs of as cast and hot rolled composite specimens with 20 vol. % of SiC shown in figs. 2 (a and b), respectively as a sample of results. These results are attributed to the breakage by hot rolling of the large particles or particle clusters of SiC and redistribution them in the matrix.

Previous work on other composites reported similar agglomeration behavior. Quantitative comparison between this work and previous works cannot be represented here because of unavailability of quantitative results in previous work.

4.3. Mechanical properties at elevated temperature

The effect of testing temperature on the ultimate tensile strength, and elongation percentage is shown in figs. 4-a and b, respectively. It is noticed that, in case of hot rolled specimens, the UTS increases slightly with increasing temperature up to 150° C then decreases with further increases of temperature. The hot rolled specimens showed higher tensile strength and elongation than the as cast specimens. These results are attributed to the reduction of grain size and porosity content by hot rolling.

The effect of testing temperature on the tensile strength and elongation of specimens of different composites is shown in figs. 5 to 8 for all used reinforcement volume fractions. The hot rolled composites retain their high strength with the increase of test temperature until a certain threshold test temperature is reached then the strength decreases slightly with the increase of temperature. The figure indicates a general tendency of increase of threshold temperature with the increase of particle volume fraction. The as cast composite specimens did not retain their high room tensile strength with the increase of test temperature. These can be attributed to a better interface bonding between the particle and matrix by the effect of hot rolling. The threshold temperature can be approximately predicated from the experimental results, which lies in the range of 150°C to 250°C depending on particle volume fraction. The ductility of both as cast and hot rolled composites increases with the increase of test temperature.

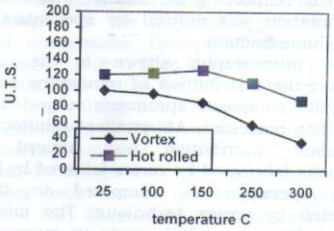


Fig. 4-a. U.T.S. in MPa versus testing temperature for unrienforced specimens.

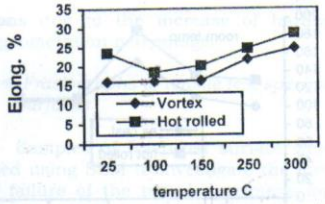


Fig. 4-b. Elongation % versus testing temperature for matrix alloy.

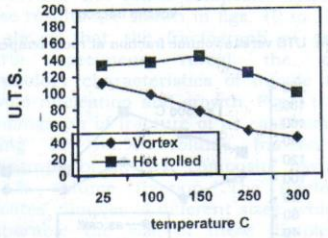


Fig.5-a. U.T.S. in MPa versus testing temperature for 8% vol. SiC composite specimens.

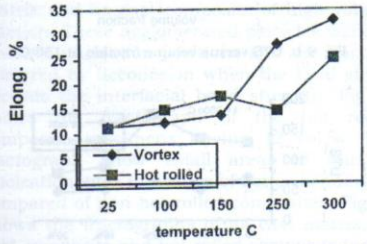


Fig. 5-b. Elongation % versus testing temperature for 8vol. %SiC Composite specimens.

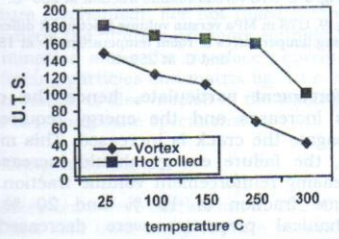


Fig. 6-a. U.T.S. in MPa versus testing temperature for 12 vol. % SiC composite specimens.

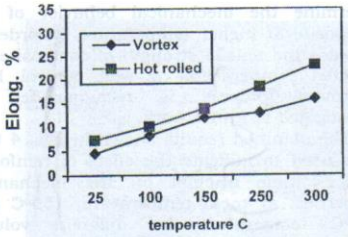


Fig. 6-b. Elong. % versus testing temp. for 12 vol. % SiC Composite specimens.

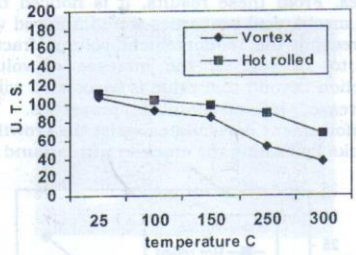


Fig. 7-a. U.T.S. in MPa versus testing temperature for 16 vol. % SiC composite specimens.

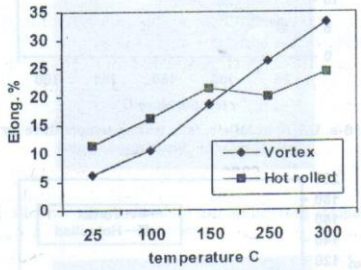


Fig. 7-b. Elong. % versus testing temp. for 16 vol. % SiC composite specimens.

As stated before, it can be concluded that, at temperature higher than 250°C, the matrix becomes soft, then the particles flow with matrix, left the voids, and reduce the resistant strength. Because the matrix metal affect significantly the composite characteristics, and

determine the mechanical behavior of the composite at higher temperature, in order to increase the tensile strength of composites at elevated temperature, a well control heat treatment process is recommended to investigated in future work.

The obtained results shown in figs. 4 to 8 were used to indicate the effect of reinforcement volume fraction on the mechanical properties, at room temperature, 150°C and 250°C temperature for different volume fraction using vortex and hot rolled techniques. Fig. 9 illustrates the affect of volume fraction on UTS for different temperatures. From these results, it is noticed that, the mechanical properties were improved with increasing the reinforcement volume fraction up to 12 vol. %, the increase of volume fraction beyond this value is associated with a decrease in mechanical properties. The reinforcement particulates resist the growth of cracks by leading the crack to turn around the

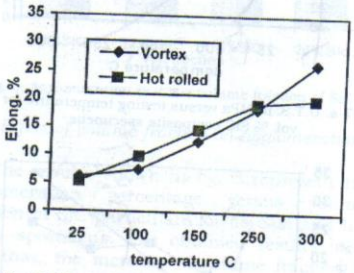


Fig. 8-a. U.T.S. in MPa versus testing temperature for 20 vol. % SiC composite specimens.

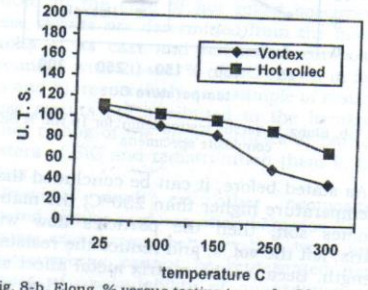


Fig. 8-b. Elong. % versus testing temp. for 20 vol. % SiC composite specimens.

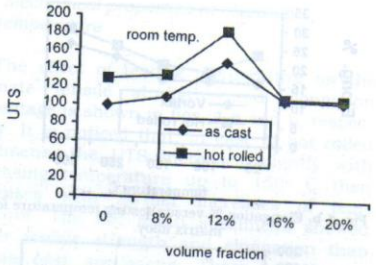


Fig. 9-a. UTS versus volume fraction at room temperature.

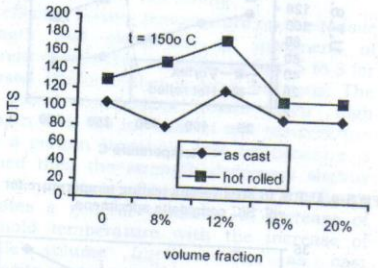


Fig. 9-b. UTS versus volume fraction at 150°C.

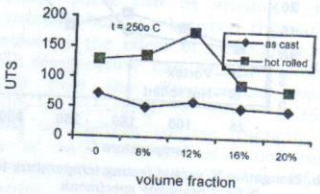


Fig. 9-c. UTS versus volume fraction at 250 °C.

Fig. 9. UTS in MPa versus volume fraction at different testing temperatures a- room temperature, b- at 150 °C and C. at 250 °C.

reinforcement particulate, hence the crack pass increases and the energy required to propagate the crack is increased. This means that, the failure energy should increase by increasing reinforcement volume fraction. For volume fraction of 16 % and 20 % the mechanical properties were decreased as compared to composites of less volume frac-

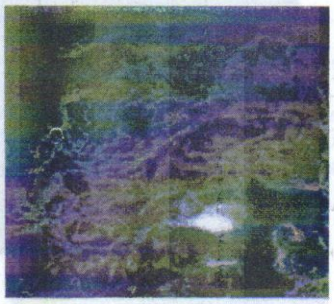
tions due to the increase of hardness and agglomeration percentage.

3.4. Fractographs of tensile test specimen surfaces

Samples of fractured surface were examined using SEM to investigate the mechanism of failure of the tested specimens for the as cast matrix, as cast composite and hot rolled matrix and hot rolled composite specimens. These results are shown in figs. 10 to 13. Fig. 10 shows that the fractograph of as cast matrix specimens reveal the dimple morphology characteristics of ductile failure by void nucleation and growth. Fig. 11 shows a micrograph of fracture of as cast composite having 12 vol.%. volume fraction. The fractograph of as cast composite having 12 vol. % volume fraction .The fractograph indicates, dimples of different sizes, which are comparable the size of these dimples are typical of the reinforcing particle size. An agglomeration of particles is noticed which is more considerable in the case of as cast matrix and as cast composite of high volume fraction. These agglomerated particles work as fracture nucleation positions and the fracture occurred by decohesion when the local stress exceeds the interfacial bond strength. Fig 12 shows the fractograph of the hot rolled composite specimens having 12 vol.%. The fractograph show small areas of fracture nucleation sites indicative of better bonding as compared of non hot rolled composites. Fig 13 shows the fractographs of as cast matrix, as cast composite and hot rolled composite tested at 300° C. For the matrix alloy the fractograph fig. 13-a indicate a typical intergranular fracture mechanism. For hot rolled composite specimens the dimples are more rounded with delamination along the interface between the reinforcing particles and matrix fig. 13-c. Such delamination is also noticed in the fractograph of as cast composite specimens.

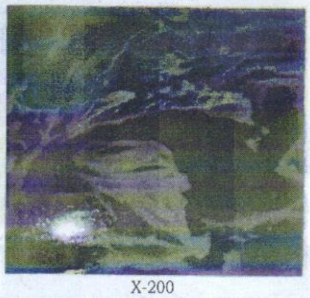
3.5. Creep test results

Creep tests were carried out at 250 °C, at a constant load until creep rapture occurs. The rupture time in hours and rupture strain were



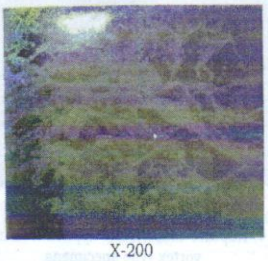
X-200

Fig. 10. Fractograph of tensile test for matrix specimen.



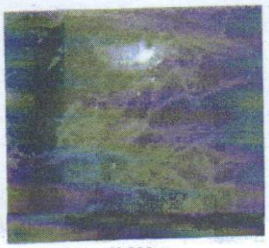
X-200

Fig. 11. Fractograph of tensile test for as cast composite specimen.



X-200

Fig. 12. Fractograph of tensile test for hot rolle composite specimen.



X-200

Fig. 13-a. Matrix as cast.

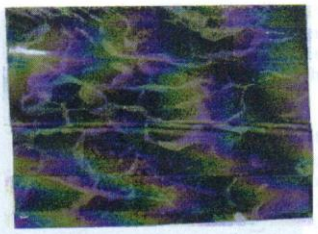
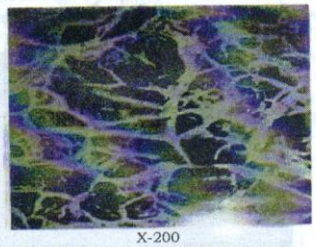


Fig. 13-b. Composite as cast.



X-200

Fig. 13-c. Composite hot rolled

Fig. 13. Fractograph of tensile test specimens at 300°C.

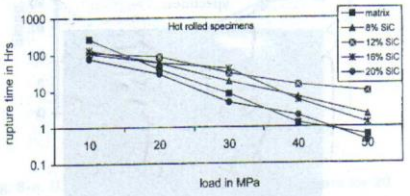


Fig. 14. Rupture time versus applied load in MPa for vortex type specimens.

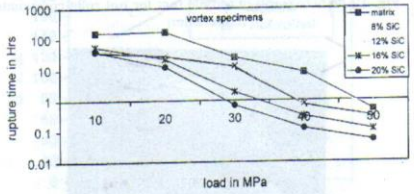


Fig. 15. Rupture time versus applied load in MPa for hot rolled specimens.

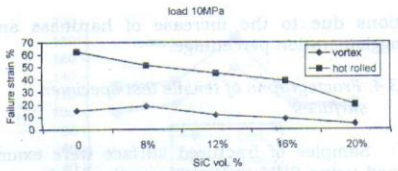


Fig. 16-a. Failure strain % versus SiC vol. % for 10 MPa applied load.

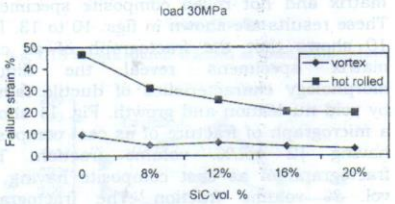


Fig. 16-b. Failure strain% SiC vol. % for 30 MPa applied load.

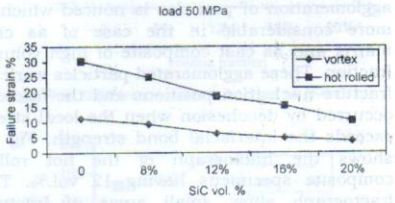


Fig. 16-c. Failure strain % versus % versus SiC vol. % for 50 MPa applied load.

recorded for each test. The obtained results are represented in figs. 14 and 15. Fig 14 represents the rupture creep time in hours versus the applied load for matrix alloy and as cast composite specimens for all test loads. The results show that, the rupture time of matrix alloy is higher than of composite specimen. The increase of volume fraction of reinforcement particles decreases the creep rupture time of the composite. These attributed to the agglomeration of particles and the high content of porosity resulting from the increase of particles volume fraction. These reduce the matrix ductility and permute decohesion between the matrix and particles.

Fig. 15 represents the creep rupture time versus the applied load of hot rolled specimens. From these results it is noticed that, except for the specimens of 20 vol. % the rupture time of all composite specimens are higher than that of the matrix alloy. The increase of volume fraction increases creep rupture time. These results emphasis's the improvements of creep rupture time by hot rolling for as cast composite. The improvements of creep strength by increasing particles volume fraction is related to the increase of energy required to crack propagation as mentioned above. The composite containing 20 vol.% showed very low creep rupture time even lower than that of the matrix alloy. This attributed to the segregation of particles during in cooperation into the liquid matrix.

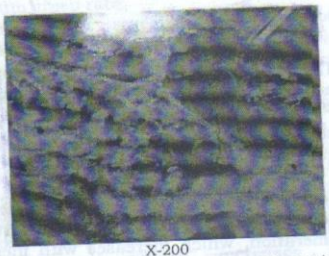
Fig 16 represent the failure strain versus volume fraction for as cast and hot rolled specimens for different applied loads. From the obtained results it is noticed that, a low failure strain was obtained or reached in as cast specimens relative to hot rolled specimens for all values of applied loads. It is noticed also that the increase of volume fraction reduces the failure strain in both as cast and hot rolled specimens. These results are related to the improved ductility by redistribution of the reinforcement particulates by hot rolling.

3.6. Fractographs of creep test specimen surfaces

Fractographs of creep test specimen's surfaces for the matrix, composite fabricated by vortex and those by vortex followed by hot rolling are shown in figs. 17, 18 and 19 respectively. The fractographs shown in fig. 17 indicates a ductile failure through void nucleation and growth. Fig. 18 and 19 show that, fracture occurs by void nucleation and growth around the grain boundaries of the matrix, while the reinforcing particles delaminate along boundary. The fracture occurs by coalescence of voids at decohered particles leading to dimpled fracture. The intergranular separation in case of as cast composite specimens; show also extensive particles clustering resulting from agglomeration phenomena.

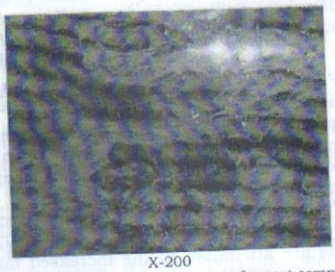
3.7. Hardness test results

Figs. 20-a and b represent the hardness in Kg/ mm^2 versus temperature for as cast and hot rolled composites, the obtained results indicate that, in the case of as cast composite, the increase of volume fraction increases the hardness while the increase of testing temperature reduces the hardness. In hot rolled



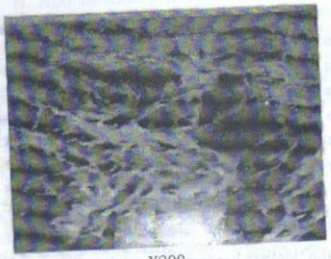
X-200

Fig. 17. Fractograph of creep test for matrix specimen.



X-200

Fig. 18. Fractograph of creep as cast for cast composite specimen.



X200

Fig. 19. Fractograph of creep test for hot rolled composite specimen.

specimens a slight effect of testing temperature on the hardness till a certain temperature depends on volume fraction, where this temperature increases by increasing volume fraction. The hot rolling operation gives a fine distribution of comminuted SiC particulate. This particulate hardening of the subsurface at elevated temperature may be responsible persisting high hardness at elevated temperature.

3.8. Impact test results

The results shown in fig. 21, indicate the impact energy measured on specimens of 1cm² cross sectional area, these result indicate that the impact energy decreases with increasing volume fraction in the case of as cast specimens. Whereas it increases with increasing volume fraction in case of hot rolled composites. The high porosity and particles agglomeration, which increases with increasing volume fraction, are responsible of this effect.

3.9. Wear test results

Fig. 22, represent the wear rate versus applied load for hot rolled matrix and composite specimens. The obtained results indicate that, the wear rate decreases by using reinforcement particulates and by increasing volume fraction up to 12 vol. %.

Further increase of volume fraction up to 20 vol. % increases the wear rate. These results are attributed to the increased matrix hardness and the number of particulates sharing in carrying applied load.

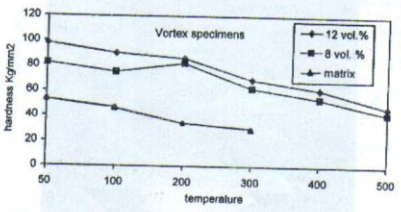


Fig. 20-a. Vickers hardness versus temperature in °C for vortex composite specimens.

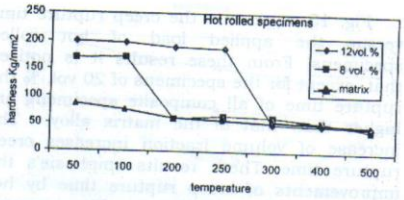


Fig. 20-b. Vickers hardness versus temperture in °C for hot rolled composite specimens.

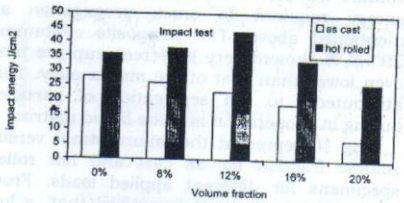


Fig. 21. Impact energy versus volume fraction at room temperature.

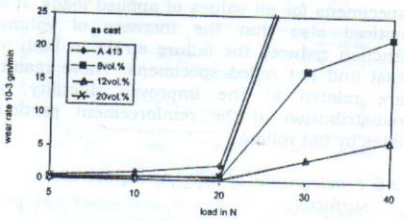


Fig. 22. Wear rate versus applied load at constant sliding speed of 2.49 m/sec and operating time of 15 min.

The results shown in fig. 23 represent the wear rate versus sliding speed, these results indicate that, the wear rate increases by increasing the sliding speed and decreased by increasing the volume fraction up to 12 vol.%. While the increase of volume fraction up to 20 vol. % increases the wear rate due to the increase of agglomeration and reduction of matrix particulate interface strength by increasing volume fraction. Hence, increases the SIC_P which separate from the matrix which work as cutting tools during sliding action.

The results shown in fig. 24 represent the wear rate versus volume fraction for hot rolled and as cast specimens. From these results it is noticed that, the hot rolled specimens have a lower wear rate than the as cast specimens for all used volume fraction. These results mean that, the hot rolling process improves tribological properties of as cast composites.

4. Conclusions

Based on the results of this on Al-alloy A 413 MMC_p fabricated using vortex and vortex combined by hot rolling process, the following conclusions can be drawn:

1. The composites manufactured by vortex combined by hot rolling process exhibited good combinations of meachanical and tribological properties.
2. The critical operating temperature were investigated from the present work, where it was noticed at 150 °C in the case of metal matrix, 200 °C in the case of vortex composite and 250 °C in the case of vortex combined by hot rolling composites.
3. Composites manufactured using vortex combined by hot rolling process showed exceptionally high values of elongation and minimum creep rate.
4. Fractography revealed that, composite specimens failed in a ductile manner with voids initiating at the site of reinforcement particulate.
5. The rupture time of composite specimens fabricated by vortex method is less than the matrix specimens for all used volume fractions. In composite specimens fabricated by vortex combined by hot rolling a highest rupture time than those of matrix specimens and vortex composite specimens is obtained.
6. The impact energy increases with increasing additive volume fraction in the case of as cast combined by hot rolling composites, while it shows a reverse behavior in the case of as cast composites.

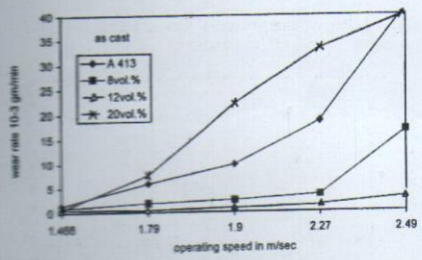


Fig. 23. Wear rate sliding speed at constant applied load of 30N and operating time of 15 min.

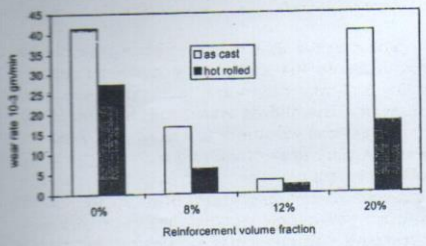


Fig. 24. Wear rate versus volume fraction of SiC particulates fr as cast and hot rolled composite specimens at constant applied load of 30 N, sliding speed of 2.49 m/sec and operating time of 15 min.

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