Roohollah Rahmanifard\textsuperscript{a}, Farshad Akhlaghi\textsuperscript{b}
\textsuperscript{a}School of Advanced Technologies, Iran University of Science and Technology, Tehran, Iran
\textsuperscript{b}School of Metallurgy and Materials Engineering, Faculty of Engineering, University of Tehran, Tehran, Iran

Characterization of A356 aluminum matrix composite affected by SiC particle size and extrusion parameters

The effects of extrusion parameters on the microstructural characteristics and the tensile properties of Al-10 vol.\% SiC composites containing three different particle sizes of 38, 62, 82 \textmu m were investigated. The results showed that the tensile properties of the composites were improved with the increase of extrusion ratio only up to 12:1 for the extrusion temperatures of 450 and 500 °C, but continued to improve at extrusion temperature of 550 °C due to the considerable reduction in porosity and appropriate alignment of reinforcing phase. Furthermore, the increased extrusion temperature resulted in improvement of elongation and tensile strength at the expense of yield strength. It was found that the extrusion treatment under the conditions of larger sized particles, lower temperature and higher ratio provided more pronounced breakage of SiC particles which could be beneficial if the broken pieces of SiC were totally embedded in the matrix.

Keywords: Hot extrusion; Extrusion temperature; Extrusion ratio; Aluminum matrix composite; Mechanical properties

1. Introduction

A356 alloy is widely used in engineering structures and components where light weight or corrosion resistance is necessary, however, it suffers from relatively poor mechanical properties [1]. Improvements of the specific modulus and strength in the composite structure of this alloy have led to its developed application in the aerospace and automotive industries [2, 3]. The most commonly used route for manufacturing aluminum matrix composites is the melt stirring method. Generally, the microstructure of composites prepared by this technique includes particle-porosity and particle-particle clusters causing an improper distribution of the reinforcing particles [4–7]. Stirring of composite slurry within a semi-solid temperature range, termed the compocasting technique, is a solution which can improve the wettability of ceramic particles due to collision between the secondary particle and the primary solidified phase and hence, provides a better macroscopic distribution of particles throughout the matrix alloy [5–7]. However, the porosity in the as-cast materials is a substantial imperfection. In addition, the density difference between the molten metal and the reinforcing particles as well as the rejection of particles ahead of the solidification front can degrade the macroscopic distribution. Therefore, a secondary deformation process such as extrusion, rolling or forging is necessary to decrease the porosity and to obtain a more uniform particle distribution due to the break-up of particle agglomerates, as well as to improve the particle-matrix interfacial bonding leading to enhanced mechanical properties [8–13]. Sharifian [8] and Mousavian [9] have reported significant fragmentation of particles after the extrusion. The studies conducted by Matthew et al. [10] indicated that 30\% forging reduction led to a greater uniformity of distribution of reinforcing particles compared to the as-cast composite. It was also found that hot extrusion reduced the porosity and increased the interfacial bonding strength [11–13].

As any change in the microstructural characteristics of particulate composite structures can alter their mechanical properties, in order to achieve the improved mechanical properties after a deformation process, it is necessary to understand how the deformation parameters affect the microstructural characteristics of a metal matrix composite. The conducted studies indicate that extrusion temperature can increase the mechanical properties of metal matrix composites (MMCs) as a result of improvement of interfacial bonding, particle distribution, density, and particle alignment. However, at very high temperatures, some defects such as surface cracking [14], banding [15, 16] or grain growth [18] may deteriorate the mechanical properties. Hence, an optimum value for the extrusion temperature is generally reported [14, 15, 16, 18]. However, it appears that such behavior is dependent on the amount of the extrusion ratio. There are no data on the latter. It has been found that the extrusion ratio also had a positive effect on the mechanical properties. Wang et al. [19] showed that high extrusion ratio was beneficial to reducing particle clusters and improving mechanical properties. Amirkhanlou et al. [20] have also found that the post-cast cold rolling process with a high reduction (95\%) gave rise to the disappearance of SiC clusters and subsequent uniform distribution of SiC particles in the matrix and thus, tensile strength and ductility were increased. Extrusion-induced cracking of particles is a main aspect of the particle evolution, which is accentuated at high deformation degrees and can have a tremendously reducing ef-
fect on the particle size. Although the break-up of particles induced by extrusion is mostly associated with a desirable particle distribution, either at high extrusion ratio or at low extrusion temperature, the micro-cracks and micro-porosities may also appear in the microstructure. Tham et al. [21] believed that processing-induced voids were eliminated by highly compressive hydrostatic stresses generated during high deformation degrees. However, Matthew et al. [10] have observed that after a certain deformation degree, the quantity of porosity and clustering was slightly increased. Also, Shi et al. [22] found that an increase in the degree of forging deformation from 40% to 60% caused enhanced localized strain and matrix hardening resulting in the matrix inability to easily squeeze into the voids and subsequent creation of new types of voids. Considering the above discussions, it appears that the formation of voids induced by particle fracture can be inhibited by the coupled effects of large hydrostatic pressures and low matrix flow stress at high extrusion temperatures.

Therefore, in this research, first, it is attempted to make a comprehensive and systematic investigation on SiC particle evolution and the variations of porosity in composites containing different sized particles due to the coupled effect of different extrusion temperatures and extrusion ratios. Then, the effects of the above processing parameters on the tensile properties are evaluated and finally, how the microstructural evolution in the presence of different sized particles can affect the mechanical properties of Al–SiC composites is clarified.

2. Experimental procedure

A356 aluminum alloy containing mainly 7.16 wt.% Si and 0.38 wt.% Mg was used as the matrix material. Melting of the alloy was done in a graphite crucible using an electrical resistance furnace. Al-10 vol.% SiC composites were produced by solid–liquid (SL) variation of the compocasting route [16]. The average size of SiC particles (d50) measured by a laser particle size analyzer (Cilas 1064), were 38, 62 and 85 μm. These particles were artificially oxidized in air at 1000 °C for 90 min to form a layer of SiO2 on the surface of the particles and to improve their wettability with the molten aluminum.

Composite slurry prepared through compocasting was poured into a cylindrical-shaped steel mold with an internal diameter of 44 mm and height of 50 mm after preheating it at 400 °C. The samples were then hot extruded by a hydraulic press at a ram speed of 1 mm s⁻¹ with three different extrusion ratios of 6:1, 12:1 and 18:1. In order to examine the effect of extrusion temperature on the microstructural and mechanical characteristics of the composite, three different extrusion temperatures of 450, 500 and 550 °C were considered. The microstructure of the as-cast and the extruded samples was examined via a Olympus light microscope and CamScan MV2300 scanning electron microscope (SEM).

3. Results and discussion

3.1. Structural characteristics

The surface finish of the specimens extruded at different conditions is shown in Fig. 1. In order to obtain a Flawless specimen, the processing parameters such as die shape and extrusion temperature were investigated. Extruding in the temperature range from 450 to 590 °C revealed that surface cracking occurred at processing temperatures above 550 °C in accordance with Fig. 1a. The latter can be attributed to the local surface melting of the matrix alloy due to the considerable increase in temperature close to the die wall. It was found that the crack depth was temperature-dependent. The appearance of surface cracks also occurred at an extrusion temperature of 450 °C. However, their shape and size were different from those observed above 550 °C so that these small cracks could easily be removed by subsequent machining. The shear stresses developed on the die wall and, consequently, the increase of fractured particles which could not be embedded in matrix alloy may be the origin of formation of such small cracks. An extensive surface cracking of AZ91 magnesium composite extruded at 350 °C at a ram speed of 2 mm s⁻¹ has also been reported by Roy et al. [23]. They believed that a narrow hot working range of composite materials and heat loss at the outer surface of the billet in die assembly could produce such cracks. However, since in the present study, no cracks were observed at the moderate temperatures between 450 and 550 °C, the heat loss cannot be a reasonable reason for the surface cracking. The effect of die shape on surface finish of the specimens is observed in Fig. 1b and c where flat and conical dies (with die angle of 45°) are used for extrusion process, respectively. As was observed, the surface cracking occurred in the specimen produced through the flat die while a flawless specimen was obtained using the conical die. It seems that abrupt change in the cross-section which occurs during deformation through a flat die can intensify the particle fracture and formation of surface cracks.

Figure 2 shows the variation of distribution factor as a function of the extrusion ratio and the extrusion temperature for Al-10 vol.% SiC composites containing different sized SiC particles compared to the as-cast samples. As can be seen, at low temperatures, an increase of extrusion ratio up to 12:1 leads to reduction of the distribution factor which means more uniform particle distribution. However, further increase of extrusion ratio slightly deteriorates this uniformity. Low deformation of those regions including particle agglomerates as well as the higher resistance of agglomerates to deformation compared to the matrix alloy,

\[
DF = \frac{S.D.}{A_f}
\]

where \(A_f\) is the mean value of the area fraction of the SiC particles measured on 100 fields of a sample and S.D. is its standard deviation. The density of the samples was measured using Archimedes’ principle according to ISO 2738 standard. Tensile specimens with gage length of 30 mm and diameter of 6 mm were machined from the as-cast and the extruded material in accordance to ASTM-E8 M. Tensile tests were performed on a MTS system at a cross-head speed of 1 mm s⁻¹. Furthermore, some microstructural features of the composites and the fracture surface of tensile specimens before and after extrusion were studied using a
compels the matrix to flow around the agglomerate, causing an increase in the shear stress applied to the surface of the particles. Therefore, the particles placed on the agglomerate surface are released and moved into the matrix because the particles mostly tend to move towards the regions with a lower flow stress [24]. This is intensified at higher extrusion ratio so that the number of released particles increases and, subsequently, they are aligned along the extrusion axis. Consequently, the primary agglomerates observed in the as-cast composite are diminished and a growth of the secondary phase embedded in the matrix is attained. A disappearance of SiC clusters in aluminum matrix has also been reported at 95% reduction of cold formed specimens [20]. However, the reinforcing particles are not uniformly distributed throughout the matrix but they are mainly rearranged close to each other and are aligned along the extrusion axis. Thus, the increased extrusion ratio can develop the banding defect resulting in undesirable distribution of particles. This can be accentuated with extrusion temperature when the softening mechanisms in the matrix are acti-

![Fig. 1. Surface finish of the specimens extruded at the temperature and the mold type of: (a) 575°C and conical, (b) 550°C and flat, (c) 550°C and conical.](image)

![Fig. 2. The variation of distribution factor of A356/SiC<sub>p</sub> composite reinforced with different sized particles versus extrusion ratio for the extrusion temperatures of: (a) 450°C, (b) 500°C, (c) 550°C.](image)
vated and the particle rotation becomes easier [16]. Therefore, at high extrusion ratio and high temperature, particle alignment readily occurs and the banding defect is encouraged. However, Ramesh et al. [25] indicated that the banded segregation of SiC particles was eliminated using favorable coating of SiC particles due to improvement of the wetting kinetics in liquid aluminum. As can be observed in Fig. 2, the distribution factor is affected by the size of reinforcing phase which can be devoted to the increased particle interspacing when larger particle size is used. It is necessary to note that although the quantity of agglomerates increases when a small particulate phase is utilized, the interspacing of these agglomerates decreases, leading to the improvement of particle distribution.

The variations of mean diameter of SiC particles as a function of extrusion ratio at different extrusion temperatures are presented in Fig. 3. As can be observed, at lower extrusion temperature, the mean diameter of SiC particles decreases with the extrusion ratio, indicating that the breakage of SiC particles is promoted at the higher extrusion ratio. However, this effect is not large. The shear stresses acting on the surface of particles are diverse. Therefore, if the stress-induced torque exceeds the critical value, rotation or breakage of SiC particles can occur. At lower temperatures in which the flow stress of the matrix is large, particle rotation is difficult, hence the predominant phenomenon is particle breakage. Shi et al. [22] have also reported that extensive cracking damage could occur at high deformation degree due to higher localized strain and matrix hardening. At higher temperatures, owing to thermally activated softening mechanisms, the flowing of matrix becomes easier, causing the particles to be aligned parallel to the extrusion axis. Moreover, at such temperatures, the local stresses around the SiC particles are released which can reduce the possibility of particle breakage. Therefore, the reduction rate of the particle mean diameter with the extrusion ratio decreases as the extrusion temperature increases. Xu and Palmiere [26] have reported a reduced fragmentation of SiC particles at high extrusion temperature due to the activation of dynamic recovery and recrystallization mechanisms. Some researchers [14, 27] also believed that lower particle breakage at high temperatures can be affected by the easier rotation of particles.

According to Fig. 3, a size-dependence of the particle breakage at the temperatures of 450 and 500 °C is obvious. As observed in this figure, the larger sized particles suffer a greater fragmentation due to their lower fracture strength arising from the higher possibility of intrinsic flaw and fine cracks within these particles [21]. Additionally, for the larger sized particles because of the higher stress concentration around them as well as the higher applied shear forces during extrusion, the particle fragmentation can be intensified. By increasing the flow stress of matrix when a high extrusion ratio or low extrusion temperature is used, the fracture event becomes more acute. Figure 4 shows the particle breakage for the specimen extruded at 450 °C with an extrusion ratio of 18:1. A study on AA1050-10 vol.% SiC composite extruded at a ratio of 12:1 and temperature of 350 °C by Them et al. [21] also showed an increase in breakage of coarser particles. They observed multiple fractures of particles along with cracks aligned to extrusion axis. Multiple fracture of a particle occurring during extrusion can increase the number of individual small SiC particles. At first glance, it is expected that the latter can produce a more uniform distribution of reinforcing particles. The SEM micrograph in Fig. 5 demonstrates that although an extensive fragmentation of SiC particle occurs, a favorable distribution is not obtained. As can be observed, the fragments are placed close together and no effective displacement of them is found. This can be improved with increasing extrusion temperatures owing to the easier flow of the matrix into particle-nucleated voids, however, the possibility of fracture is reduced at such temperatures.

Fig. 3. The variation of mean diameter of SiC particles as a function of extrusion ratio for extrusion temperatures of: (a) 450 °C, (b) 500 °C, (c) 550 °C.
The variations in porosity for the Al-10 vol.% SiC composites extruded at different extrusion ratios and temperatures containing different particle sizes are seen in Fig. 6. As can be seen, the extrusion process mainly reduces the porosity of the as-cast material. During the extrusion process, the combination of compressive hydrostatic stresses and the shear stresses applied to the matrix cause the voids to be removed or contracted and flattened parallel to the extrusion direction (Fig. 7). These are intensified at higher extrusion ratios, hence, it is expected that the porosity is reduced with the extrusion ratio. However, as was earlier discussed, particle fracture is an unavoidable event occurring during deformation and can form inter-particle microvoids due to inappropriate flow of the matrix alloy. The latter is in contrast to the former to reduce porosity. Therefore, at high extrusion ratios, the extent of porosity reduction is lowered and even an increase in porosity may be seen. A similar result has been reported by Matthew et al. [10] when the deformation degree changed from 30% to 50%. Tekman et al. [12] have also measured the porosity for the

Fig. 4. Particle breakage in Al matrix composite containing 38 μm sized SiC particles extruded at 450 °C with extrusion ratio of 18:1.

Fig. 5. Fragmentation and redistribution of SiC particles within composite material extruded at 550 °C containing 85 μm sized particles.

Fig. 6. The variation in porosity for A356/SiCp composites containing different particle sizes as a function of extrusion ratio for extrusion temperatures of: (a) 450 °C, (b) 500 °C, (c) 550 °C.
extruded Al–Si–Mg–SiC$_p$ composite. They found that by increasing the extrusion ratio, the large-sized pores were mostly eliminated but full density was not attained due to particle fracture and formation of micro-voids. More matrix hardening at high deformation degree has also been suggested as being responsible for the inability of matrix to fill the particle fracture-induced voids [22]. High extrusion temperature also reduces the porosity of Al–SiC$_p$ composite which can be linked with the reduction of fragmentation (Fig. 3) and easier flowing of matrix alloy into the micro-voids. Hong et al. [14] have also reported an improved relative density of Al2024–SiC$_w$ when the extrusion temperature was changed from 470 to 530 °C at an extrusion ratio of 15:1.

It is worth noting that the porosity is affected by the size of SiC particles. With regard to Fig. 6, an opposing behavior is found for the as-cast and the extruded material with the exception of extruding at a ratio of 6:1 for 450–500 °C. In the as-cast material, the larger the particle size, the lower will be the porosity, whereas it occurs inversely in the extruded material arising from particle-breakage nucleated micro-voids. However, as was mentioned above, for the specimen extruded at the ratio of 6:1 for 450–500 °C, the porosity is decreased with increased particle size. The origin can be sought in the porosity of the as-cast material, low deformation degree and weak flow of the matrix alloy. The study of El-Kady and Fathy [28] on the effect of SiC particle size on the physical properties of extruded Al-matrix composite also indicated an increase in density as the SiC particle size increased. This was attributed to higher compressibility of the composite powder containing coarser sized particles. However, by increasing the extrusion temperature and ratio, the extent of porosity reduction is stimulated especially for the finer sized particle-containing composites.

3.2. Mechanical properties:

The effects of temperature and ratio of extrusion on the yield strength of Al-10 vol.% SiC composite are shown in Fig. 8. As can be seen, the yield strength of as-cast composite material is higher than that of the base alloy due to the following reasons. The particulate phase not only bears a small fraction of applied load, but also acts as an obstacle to dislocation motion. In addition, the significant difference between thermal expansion coefficients of the matrix and the secondary ceramic phase can also increase the dislocation density in the matrix.

As can be seen in Fig. 8, for both the as-cast and the extruded composites, the yield strength increases as the particle size is reduced. The high number density of the particles in the fine particle-reinforced composites leads to increased obstacles to dislocation motion and subsequently enhanced dislocation density. Furthermore, since the particle distribu-
tion in such composites is more uniform compared to the coarse particle reinforced composites (Fig. 2), the inter-particle distance decreases and a more homogeneous distribution of dislocations may be concluded. Meanwhile, according to the Orowan mechanism, the required stress to bypass the dislocation through the reinforcing particles increases by decreasing the inter-particle distance. Deformation degree is also an effective parameter to achieve improved yield strength. As the dislocation interaction is developed by increasing the deformation degree, the required stress to start the motion of dislocation increases. Therefore, the effect of extrusion ratio on the yield strength of composites is positive. This result is in agreement with the literature [19, 20].

According to Fig. 8, an increase in extrusion temperature from 450 to 500 °C results in a slight reduction of the yield strength. Further increase of the temperature from 500 to 550 °C causes the extent of reduction to be intensified. At high temperatures, the tangles of dislocations accumulated behind the obstacles are released by the cross-slip or climb mechanisms, thus the yield strength is decreased as a consequence of dislocation density reduction. However, the higher the extrusion ratio, the lower the degree of reduction in yield strength is. At high extrusion temperatures, the particle size dependence of the yield strength is also not considerable. As can be observed, the yield strength is reduced very slightly or nearly remained unchanged. In other words, the error limit of measured data covers the extent of variations of yield strength influenced by particle size. However, Hashiguchi et al. [29] reported that a higher yield strength could be reached by using sub-micron rather than micrometric SiC particles.

Effect of temperature and ratio of extrusion on ultimate tensile strength (UTS) and elongation are shown in Figs. 9 and 10, respectively. As can be seen, extruding of as-cast composites improves their tensile strength due to reduction of porosity, improvement of the particle–matrix interfacial bonding and disintegration of the void–particle agglomerates.

With regard to Fig. 9, it is found that the tensile behavior of composite materials versus extrusion ratio experiences a change at high extrusion temperatures. At extrusion temperatures of 450 and 500 °C, the tensile strength of the composite material is improved with the increase in extrusion ratio only up to 12:1 but continues to improve at an extrusion temperature of 550 °C. The following mechanisms could be involved; a – twofold behavior of the porosity content with extrusion ratio at low temperature (Fig. 6) so that it increases markedly up to the ratio of 12:1 and remains nearly unchanged for higher ratios; b – the considerable fracture of particles at low extrusion temperature degrading the load-bearing surface, but decreases with the increased temperature; and c – the pronounced particle alignment due to the increased extrusion ratio which can give improved strength.

At a temperature of 450 °C, the degree of alignment of SiC particles is low but in turn the breakage of particles occurs violently. Thus, it seems that fragmentation is the dominant mechanism at low extrusion temperature, hence by increasing the extrusion ratio from 12:1 to 18:1, the tensile strength decreases. At an extrusion temperature of 500 °C, the extent of fragmentation is slightly decreased and in turn the alignment of particles is encouraged. In addition, regarding considerable reduction in porosity from a ratio of 6:1 to 12:1, an increased tensile strength is expected. However, as has been mentioned above, the microstructural studies demonstrate the degradation of the particle distribution and intensification of particle fracture at higher extrusion ratios. In addition, the porosity reduction is also nearly stopped. Consequently, the increase in extrusion ratio from 12:1 to 18:1 can lead to a reduction in the tensile strength. A similar trend has been reported in literature on aluminum matrix composites [12, 13]. They presented particle fracture as the main reason for deteriorating mechanical properties above a critical extrusion ratio. As has been aforementioned, the matrix alloy flows more easily into the crevices and inter-particle voids at a temperature of 550 °C, thus resulting in improved interfacial bonding

Fig. 9. The variation of ultimate tensile strength (UTS) for A356/SiCp composites containing different particle sizes as a function of extrusion ratio for extrusion temperatures of: (a) 450 °C, (b) 500 °C, (c) 550 °C.
Furthermore, the lower possibility of particle damage and their easier alignment arising from the reduced stress generated during deformation are two other reasons which can aid promotion of the load-bearing surface of particles. With increasing extrusion ratio at the above-mentioned temperature, the extent of particle fracture increases slightly, but the particle alignment and the reduction of porosity are also promoted leading to improved ultimate tensile strength. Hong et al. [14] presented increased density as the main reason for a 20% improvement of tensile strength when the temperature was changed from 470 to 530°C. In another study [19], the evolution in the particle size and more uniform distribution of particles were expressed as important parameters for the improvement of tensile strength at high extrusion temperature and ratio. However, some reports show that there is a modified extrusion temperature to reach the maximum tensile strength [17, 30]. For example, in Mg-matrix composite [17] and Al matrix reinforced with an intermetallic particulate phase [30], respectively, the generation of a new precipitating phase and the increased ductility of the intermetallic phase above a certain temperature have been presented as the reasons for the decrease in strength.

It is evident from Fig. 9 that the tensile strength of the matrix alloy also increased significantly at 550°C. As can be seen, the tensile strength of the extruded matrix alloy is 215 MPa which is about 44% higher than that of the as-cast matrix alloy. It is interesting to note that the tensile strength of both matrix and the reinforced alloy is nearly identical at such temperature. It seems that extruding at high temperature can provide a near-to-theoretical density for the unreinforced alloy, thus the stress concentration points decrease markedly during tensile testing, resulting in increased stress to failure of the materials, while the presence of some porosity in the composite material especially induced by particle breakage is unavoidable which can reduce the room temperature mechanical properties.

From Figs. 9 and 10, it can be found that there is concomitant growth of the tensile strength and elongation when the extrusion temperature increases, whereas, generally any increase in the tensile strength occurs at the expense of elongation. There are similar results on the improvement of both tensile strength and elongation in extruded composites [18–20, 31]. However, at low extrusion temperatures, the cracks developed in the particle-surrounding matrix (Fig. 11) induced by superior accumulations of dislocations around the particles can propagate and join together during tensile testing leading to abrupt failure of the specimen.
and decreased elongation. Figure 12 compares the fracture surface between the extruded and the as-cast composites. As can be observed, while interfacial de-bonding in the as-cast composite is a predominant mechanism, the fracture surface of the composites extruded at high temperature shows a dimpled structure along with SiC particles located in their centers, implying strong interfacial bonding between the matrix and the reinforcement.

According to Figs. 9 and 10, the specimens containing larger sized particles have a slightly lower tensile strength and elongation. The more pronounced breakage of these particles during extrusion enhances micro-porosity and crack initiation, thus the tensile failure occurs at a lower stress level. At the lowest extrusion ratio, an inverse behavior is observed so that the tensile strength shows an increase for larger sized particles. This can be attributed to high porosity in the as-cast composite reinforced by the smaller sized particles as well as subsequent low degree of deformation. In addition, the possibility that inadequate flow of the matrix at low extrusion temperatures and ratios cannot effectively aid reduction of the porosity is not to be excluded. Therefore, the interfacial de-bonding and micro-voids are the main origins of failure of the composite in these regimes. As can be observed, with increasing temperature and ratio of extrusion, the tensile strength of these materials experiences a remarkable increase compared to the above conditions.

4. Conclusion

The effects of temperature and ratio of extrusion on characteristics of Al-10 vol.% SiC composite containing different sized particles were investigated. Based on the microstructural and mechanical analyses, the following conclusions are drawn:

1. Hot extrusion of A356–SiC₆ composite using a flat die induced surface cracks throughout the specimen, while extruding through a conical die with an angle of 45° in the temperature range of 450–550°C produced a flawless specimen.

2. At the extrusion temperatures of 450 and 500°C, the increase of extrusion ratio only up to 12:1 improved the tensile properties of composite material as a result of improvement in the particle distribution and reduction of porosity. However, at the extrusion temperature of 550°C, due to considerable reduction in porosity and pronounced alignment of the reinforcing phase, a continuous trend in improvement of tensile properties with increasing extrusion ratio was observed.

3. The effect of break-up of SiC particles on the tensile properties was detrimental at low extrusion temperature but was beneficial at high temperature due to easier flow of the matrix alloy into the particle-fracture-induced micro-voids. However, low displacement of broken pieces of SiC particles during extruding of composite material was an obstacle to achieving the desirable distribution of particles and in turn improved mechanical properties, especially when the larger particle size was used.

4. At low extrusion temperatures, the cracking of SiC particle-surrounding matrix had a profound impact on degradation of elongation and tensile strength of the composite material.

References
