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Elevated temperature tensile properties of squeeze-cast Al–Al_2O_3–MgO particulate MMCs up to 573 K

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Al–Al_2O_3–MgO squeeze-cast composites were prepared using a modified "MgO-coating" technique and their tensile behaviour up to 300 °C (573 K) evaluated. In each case, 10 wt% total powder mixture (Al_2O_3 + MgO) containing 15% MgO was stirred into well-superheated Al melt and the stirred slurry was squeezed in the pressure range 80–140 MPa using a 60 t semi-automatic hydraulic press and alloy-cast iron dies. The tensile behaviour at 100, 200 and 300 °C (373, 473 and 573 K) of the squeezed composites (70 mm diameter, 60 mm long) was then examined. It was found that the composite squeezed at 140 MPa and ambient die temperature displayed the best tensile properties up to 573 K, the ultimate tensile strength (UTS) values being 207.9, 197.8, 179 and 160.4 MN m^{-2} at ambient, 373, 473 and 573 K, respectively. Compared to ordinary gravity chill-cast composite, the UTS of the above composite was higher by 52% at 373 K. This value rose to 161% and 162% at 473 and 573 K, respectively. The above composite retained about 77% of its ambient UTS value at 573 K, while the ordinary gravity chill-cast composite retained only 44% of its ambient UTS value. The performance of the squeezed composite with regard to 0.2% offset yield strength (YS) was distinctly superior to the gravity chill-cast composite. The YS values for the squeezed composite were 119.5, 117.3, 115 and 112.8 MN m^{-2} at ambient, 373 K, 473 K and 573 K, respectively. The squeezed composite retained 94.4% of its ambient YS value at 573 K, while the gravity chill-cast composite retained only 47.6% of its ambient YS value at the same test temperature. The YS of squeezed composite was higher by 105% compared with the YS value of gravity chill-cast composite at 573 K. The performance of the squeezed composite progressively improved compared to gravity chill-cast composite as the test temperature was systematically raised to 573 K. Squeezed composites also exhibited fully ductile fracture features compared to semi-ductile to brittle fracture features of the gravity chill-cast composites; they also perform better because of the virtual absence of porosity and some degree of grain refinement obtained upon squeezing. Increasing the squeeze pressure in the range 160–240 MPa is likely to improve the properties of the composite further.

1. Introduction

A number of cast particulate metallic matrix composites (MMCs) have been developed and characterized using a wide variety of fabrication techniques and a variety of dispersoid particles, such as graphite, Al_2O_3, SiC, ZrO_2, mica, illite-clay, shell char etc. [1]. Depending upon their characteristics, individual cast particulate MMCs are intended for specific end applications. Among all these composites, Al–Al_2O_3 and Al–Al_2O_3–MgO systems are known for their high-temperature tensile properties and hardness up to 350 °C and superior adhesive wear resistance compared to pure aluminium [2–5].

Recent studies on cast particulate MMCs prepared by the "Vortex liquid metallurgy route" or the "compocasting" technique have revealed that they suffer from a considerable amount of porosity [6–10]. Total porosity in such composites may consist of gas porosity plus interdendritic unfed regions [10]. The result is that gravity chill-cast composites undergo premature failure and the fractured surfaces of tensile specimens show semi-ductile to brittle fracture features together with the presence of large voids pulled and enlarged under tension [10–13]. In other studies, the relationship between the strength of cast Al alloy–Al_2O_3 composites and the level of porosity present has been quantified [6–9]. It is, therefore, apparent that because of the presence of these voids, the full potential of the gravity chill-cast composite in terms of the mechanical properties achievable is never realized in practice.

One possible means of decreasing porosity levels to the bare minimum could be liquid-forging or squeeze casting of the stirred slurry [10–13]. This practice has been adopted extensively in recent times to improve property performance levels of a number of alloys and

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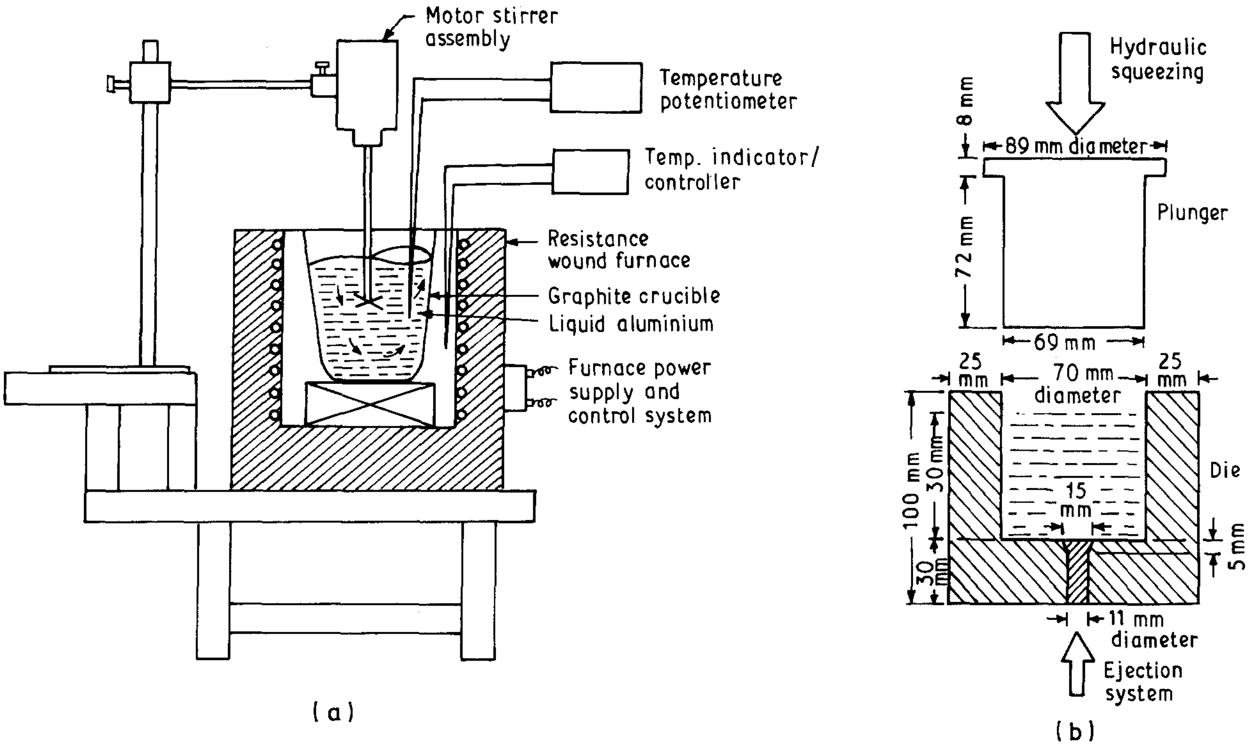


Figure 1 Schematic diagram showing the experimental apparatus (a) for the preparation of the stirred slurry, and (b) for the squeeze casting of stirred slurry.

composite systems [14–16]. Recent studies on the Al–Al_2O_3–MgO composite system have shown that squeezing the stirred slurry in the pressure range of 80–140 MPa results in greatly improved tensile properties of the composites at ambient temperature [11–13]: not only the ultimate tensile strength (UTS) of the composite is considerably improved but also the ductility indicated by per cent elongation is simultaneously improved with progressive increase in the squeeze pressure applied. This gives rise to almost fully ductile fracture features of the composite squeezed at 140 MPa and ambient die temperature, which also possessed the best tensile properties [11–13].

The overall advantages offered by the squeeze-casting process should result in improved property performance levels of Al–Al_2O_3–MgO composites at elevated temperatures too, for which they are basically designed and known. A detailed study of this aspect is presented in this paper.

2. Experimental procedure

2.1. Preparation of the stirred slurry

The "modified MgO-coating" technique developed recently [10–13], together with the vortex liquid metallurgy route [2–5], was adopted for the preparation of the stirred slurry. It was necessary to modify the standard "MgO-coating" technique developed earlier [3–5], for application under humid environmental conditions such as exist in this region, in order to result in the usual 12%–14% V_f retention of Al_2O_3 in the base matrix.

Briefly, the "modified MgO-coating" technique requires that the well superheated aluminium melt (860 °C) is degassed fully with hexachloroethane tablets (10 g/1100 g melt), followed by Mg plunging to the tune of 0.5% melt. The objective is to decrease the H_2 potential of the bath so that suitable energy conditions are created for the incorporation and retention of Al_2O_3 particles in the stirred slurry. In addition, the powder mixture (Al_2O_3 + MgO containing 15% MgO) amounting to 10 wt % melt is heat treated at 900 °C for 2 h to dehydroxylate fully the surfaces of the particles [2]. During addition, the powder mixture is maintained at $\approx 200\,°C$ to prevent any absorption of moisture. The heat-treated and fully dried powder mixture is then added gradually along the walls of the vortex created in the melt with the help of a marine blade impeller of suitable diameter. The stirring of melt is continued for nearly 90 s to incorporate the powder mixture fully, and the slurry is poured at 800 °C. α-Al_2O_3 particles employed in the present work conformed to the size range 40–150 μm, while the submicrometre MgO particles conformed to 0.2–0.3 μm size range. Details of the blending of the two powders in order to obtain an MgO coating around the Al_2O_3 particles, and the selection of the correct level or amount of this powder mixture to be stirred into the melt, are reported in detail elsewhere [3–5].

The experimental apparatus employed for the preparation of the stirred slurry is depicted in Fig. 1a.

2.2. Squeezing the stirred slurry

The stirred slurry was squeezed in the pressure range 80–140 MPa using a 60 t semi-automatic hydraulic press and alloy-cast iron die and plunger of dimensions shown in Fig. 1b. The squeeze pressure was increased in steps of 20 MPa.

A metered quantity of clean slurry was poured in the die for squeezing. A time of 4–6 s was spent in the process of transferring the slurry to the die and then fixing the die and plunger together under the press for squeezing. In each case, the slurry was squeezed for 40 s. In the present work, the die temperature was also varied as ambient, 100 and 200 °C. After completion of the squeezing operation, the product was ejected from the die using the ejection system. Squeezed cylindrical castings, 70 mm diameter and 60 mm long, were obtained this way.

It should be mentioned that both the die and plunger surfaces were thoroughly dried and dressed with colloidal graphite powder suspended in acetone, prior to their use.

Using the same stirred slurry, some gravity chill-cast castings, 40 mm o.d. and 125 mm long, were also prepared to obtain comparative property performance data.

2.3. Optical and SEM observations

Standard optical and quantitative metallographic techniques were employed to ascertain the nature of the distribution of Al_2O_3 particles in the base-matrix and to determine percentage V_f retention of Al_2O_3 and the mean dendritic arm spacing of composites prepared under different experimental conditions.

Fractured surfaces of tensile specimens pulled at different test temperatures were examined by SEM to ascertain the mechanism of fracture operative in gravity chill-cast and squeezed composites. This was expected to reveal clearly the advantages to be gained from the squeeze-casting operation.

2.4. Tensile property evaluation up to 300 °C (573 K)

Tensile properties of gravity chill-cast and squeezed composites were determined using a 5 t Universal Instron testing machine, Model T.T.C., M.C. at a constant crosshead speed of 5×10^{-4} m min^{-1}, yielding a conventional strain rate [17] of 3×10^{-4} s^{-1} on a specimen gauge length of 25×10^{-3} m. Dimensions of a standard tensile specimen employed in this work are shown in Fig. 2. The tests were performed at ambient (25 °C), 100, 200 and 300 °C. For a commercial pure aluminium sample, it was necessary to perform the test at 225 °C only instead of 300 °C, because the strength of the material deteriorated sharply above 200 °C.

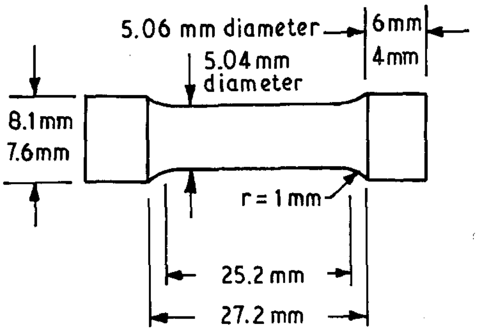


Figure 2 Schematic diagram showing the dimensions of a standard tensile specimen.

A 2 kW Kanthal resistance wound furnace of adequate inner volume was used in the test position to cover the tensile grips and the specimen fully. Furnace openings were then sealed properly from both ends. A thermocouple set close to the windings and attached to a temperature control system helped to regulate the temperature of the furnace to within ±2 °C of the pre-set test temperature. Another thermocouple was positioned close to the centre of the gauge length of the tensile specimen. Each sample was then homogenized for a period of 30–40 min at a pre-set test temperature prior to applying the load.

3. Results and discussion

3.1. Modified "MgO-coating" technique and the resulting composite

As reported earlier [10–13], the standard "MgO-coating" technique [3–5] needs to be modified for application under humid environmental conditions such as exist in this region. The modified "MgO-coating" technique results in the usual 12%–14% V_f retention of Al_2O_3 and a fairly uniform distribution of these particles in the base matrix [10–13] (Fig. 3). Some coagulation of Al_2O_3 particles seen in Fig. 3 is due to inherent limitations of the "liquid metallurgy" route [4, 5]. The role of hydrogen potential of the aluminium melt in either causing rejection or retention of dispersoid Al_2O_3 particles in the stirred slurry is being investigated presently using a hot-extraction technique [18] of estimating the dissolved H_2 content of the melt. Results of this study will be reported shortly. At present it is believed that the H_2 potential of the melt influences drastically the interfacial energies and contact angles between the dispersoid particles and the melt. This aspect is vital particularly in view of the poor wettability conditions existing between the melt and dispersoid Al_2O_3 particles [2, 19].

It was also confirmed through another set of experiments involving only the Al–MgO system that submicrometre MgO particles do cause dispersion

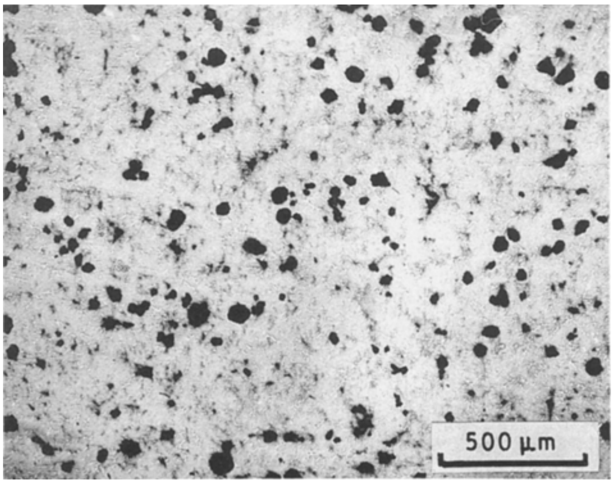


Figure 3 Optical micrograph showing the uniform distribution of Al_2O_3 particles in the composite.

strengthening of aluminium base matrix [12]. This confirms the postulate proposed earlier [3–5]. Thus, the resulting Al–Al_2O_3–MgO cast particle MMCs would be stiffened both by coarse Al_2O_3 particles and submicrometre MgO particles.

3.2. Role of squeeze-casting the stirred slurry

The advantages accruing from the process of squeezing the stirred slurry are well known and outlined in earlier publications [10–13].

Basically, the process of squeeze casting would result in the fabrication of a densified and grain-refined composite. Such a composite would show bare minimum porosity levels and would therefore exhibit much improved property performance levels. It was shown in previous studies [10–13] that when the stirred slurry is squeezed in the pressure range 80–140 MPa using three die temperatures, namely ambient, 100 and 200 °C, the properties of the composite uniformly improve. The composite squeezed at 140 MPa and ambient die temperature displayed the best properties. The density of this composite was higher by 3.681% compared to the gravity chill-cast composite. This signifies a proportionate decrease in the porosity level of the composite which is vital for its performance in tension. The mean dendritic arm spacing of this composite was found to be only 12 μm compared to 46 μm for the gravity chill-cast composite. These factors also give rise to the best HV_5 and $HM_{5\,g}$ values attained in this composite (73 and 87, respectively) compared to 41 HV_5 and 59 $HM_{5\,g}$ values for the gravity chill-cast composite. All these characteristics of the squeezed composite together would be expected to influence directly its behaviour in tension. It was reported recently [12, 13] that the UTS of the above squeezed composite (207.9 $MN\,m^{-2}$) is higher by 53% compared to the gravity chill-cast composite (136.3 $MN\,m^{-2}$). However, what is even more significant is that not only the UTS, but also the ductility, of the composite indicated by per cent elongation, is improved simultaneously as the squeeze pressure is systematically raised. The present elongation of the composite squeezed at 140 MPa and ambient die temperature is higher by 133% compared to the gravity chill-cast composite [12, 13]. This value is $\approx$ 85% of that of the composite squeezed at 80 MPa and ambient die temperature. It was also found from these studies that the properties of the composite uniformly deteriorate as the die temperature is systematically raised.

The typical characteristics of squeezed composites mentioned above would also be expected to result in improved tensile behaviour of such composites at elevated temperatures.

3.3. Tensile behaviour of squeezed composites up to 300 °C (573 K)

The results of this study are recorded in Table I and the vital data are plotted in Figs 4–10.

It can be seen from the results that the performance of the composite gradually improves as the squeeze pressure is systematically raised from 80–140 MPa. Figs 4 and 5 show this comparison of performance. Per cent elongation data are plotted in Figs 6 and 7 for different test temperatures separately in order to avoid overcrowding of points. The data derived from Figs 4 and 5 are plotted in Figs 8–10 showing per cent drop in UTS and 0.2% offset yield strength in Figs 8 and 9, respectively, and the ratio of YS/UTS in Fig. 10.

The gravity chill-cast composite loses strength faster at the elevated test temperatures compared to squeezed composites. Increasing the squeeze pressure

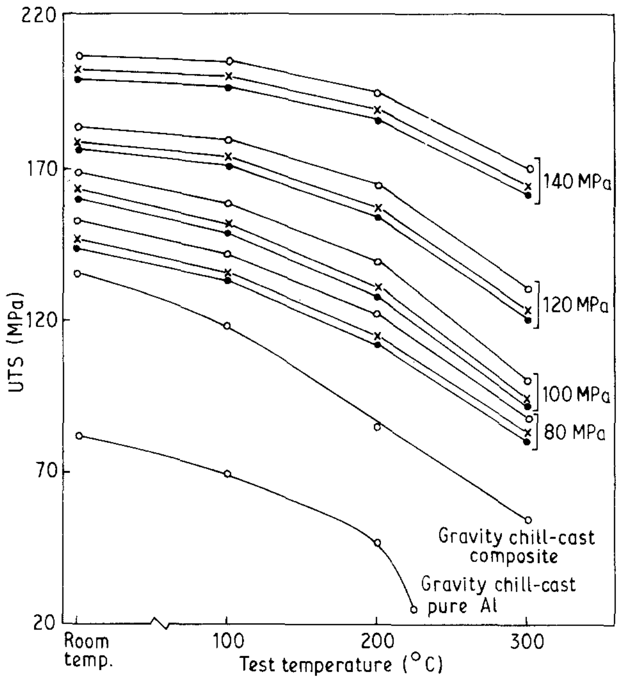


Figure 4 UTS of gravity chill-cast and squeezed composites shown as a function of the test temperatures. Squeezed composites prepared at three die temperatures: (○) ambient, (×) 100 °C, (●) 200 °C.

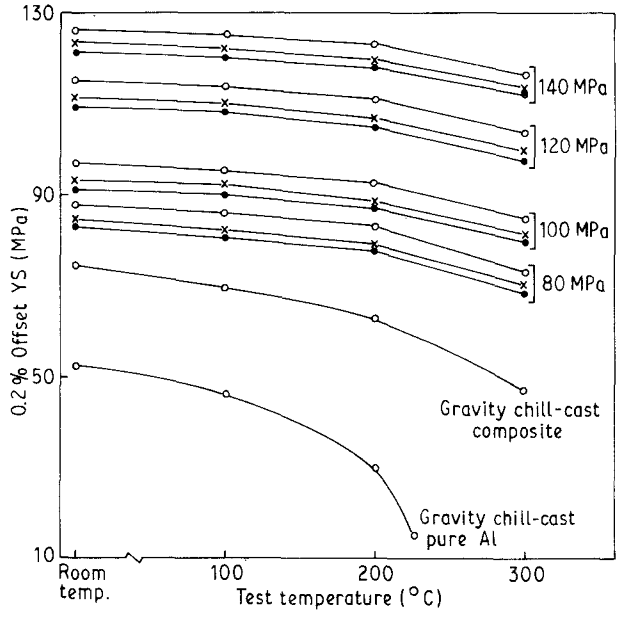


Figure 5 0.2% offset YS of gravity chill-cast and squeezed composites shown as a function of the test temperatures. Squeezed composites prepared at three die temperatures: (○) ambient, (×) 100 °C, (●) 200 °C.

TABLE I Elevated temperature tensile properties of Al–Al_2O_3–MgO squeeze-cast particulate composites up to 300 °C (573 K)

No.	Material	Squeeze pressure (MPa)	Die temperature (°C)	% V_f retention of Al_2O_3	Mean dendritic arm spacing (μm)	UTS (MN m^{-2})				0.2% Offset YS (MN m^{-2})				% Elong. on 25 × 10^{-3} m gauge length				% Reduction in cross-sectional area			
						Ambient	100 °C	200 °C	300 °C	Ambient	100 °C	200 °C	300 °C	Ambient	100 °C	200 °C	300 °C	Ambient	100 °C	200 °C	300 °C
1.	Commercially pure Al	Nil	–	–	48	84	58.6	51.1	26.6 (225 °C)	56.0	43.3	34.6	13.3 (225 °C)	19.3	41	50	65 (225 °C)	19.0	37	44	60 (225 °C)
2.	Composite	Nil	–	12.30	46	136.3	119.7	68.5	61.1	115.6	76.4	61.1	55.0	5.7	10	15	26	5.5	10	14	23
3.	Squeezed composite	80	Ambient	12.40	30	168.1	130.4	116.6	99.3	87.1	85.6	84.0	75.2	7.2	13	18	28	6.6	12	19	25
4.	Squeezed composite	80	100	11.61	34	165.0	127.8	111.6	96.8	86.1	81.5	78.9	73.5	8.0	16	22	30	7.5	16	23	29
5.	Squeezed composite	80	200	13.83	36	163.0	121.7	109.1	94.2	84.5	78.9	71.3	67.6	10.3	20	27	35	10.0	20	26	32
6.	Squeezed composite	100	Ambient	12.90	24	180.3	144.6	135.0	114.6	94.6	93.8	88.7	85.1	8.6	18	27	34	8.0	16	26	32
7.	Squeezed composite	100	100	12.02	29	173.2	141.6	132.4	112.5	91.7	90.0	85.6	84.0	9.4	21	30	37	8.8	20	30	36
8.	Squeezed composite	100	200	13.40	32	172.1	140.0	127.8	109.1	89.9	84.0	82.8	72.3	11.4	26	35	41	19.9	24	33	39
9.	Squeezed composite	120	Ambient	12.20	19	185.9	163.0	147.7	132.9	100.3	97.0	94.3	90.8	10.4	22	31	39	9.9	20	30	37
10.	Squeezed composite	120	100	12.30	22	183.3	159.1	145.1	126.3	97.8	94.4	91.7	90.1	11.2	25	34	42	10.6	25	35	41
11.	Squeezed composite	120	200	11.88	24	181.8	147.7	132.4	122.2	95.6	90.7	82.1	77.4	13.5	30	39	46	13.1	28	38	44
12.	Squeezed composite	140	Ambient	12.70	12	207.9	197.8	179.0	160.4	119.5	117.3	115.0	112.8	13.3	25	35	45	12.8	22	34	43
13.	Squeezed composite	140	100	11.78	16	198.6	168.1	152.8	142.6	108.5	103.6	95.7	94.2	13.9	28	38	47	13.8	26	36	44
14.	Squeezed composite	140	200	11.99	18	193.3	166.2	150.8	138.1	102.9	101.0	94.2	91.7	16.5	33	42	51	16.1	32	40	48

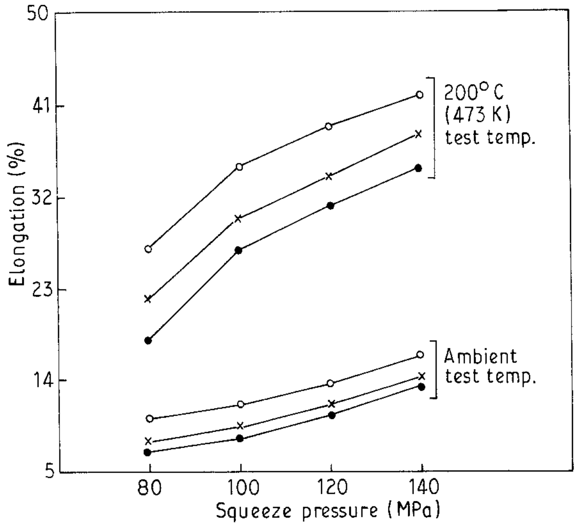


Figure 6 Per cent elongation of squeezed composites obtained at ambient and 200 °C test temperatures shown as a function of the degree of squeeze pressure applied at three die temperatures: (○) ambient, (×) 100 °C, (●) 200 °C.

in steps gradually improves the performance of the composite up to 300 °C (573 K) test temperature. Also, it can be seen that increasing the die temperature uniformly deteriorates the properties of the composite at any level of squeeze pressure applied. The best performance is exhibited by a composite squeezed at 140 MPa and ambient die temperature (Figs 4 and 5). The UTS of this composite is higher by 52.53% compared to gravity chill-cast composite at 100 °C (373 K) test temperature. This figure increases to 161% and 162.5% at 200 °C (473 K) and 300 °C (573 K) test temperatures, respectively. This analysis brings out the real benefit to be gained from the squeeze-casting process; that the composite squeezed at 140 MPa and ambient die temperature retains its strength better up to 300 °C (573 K) compared to ordinary gravity chill-cast composite. This composite retains about 77% of its ambient UTS value at 300 °C (573 K) test temperature, while the gravity chill-cast composite retains only 44% of its ambient UTS value. It would be expected that the performance of these composites would improve further if the degree of squeeze pressure is taken to still higher levels, such as

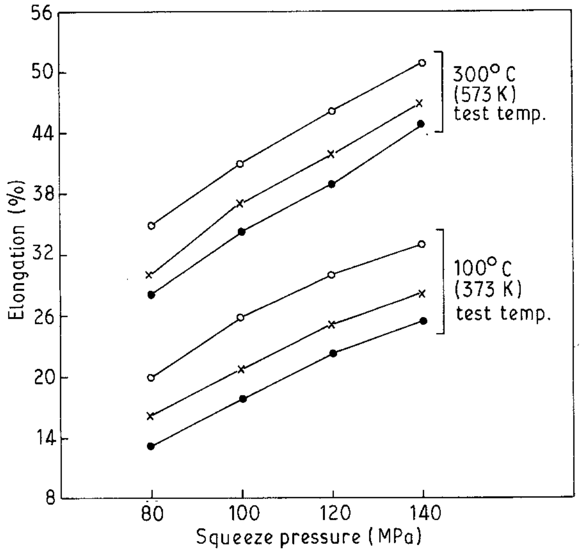


Figure 7 Per cent elongation of squeezed composites obtained at 100 and 300 °C test temperatures shown as a function of the degree of squeeze pressure applied at three die temperatures: (○) ambient, (×) 100 °C, (●) 200 °C.

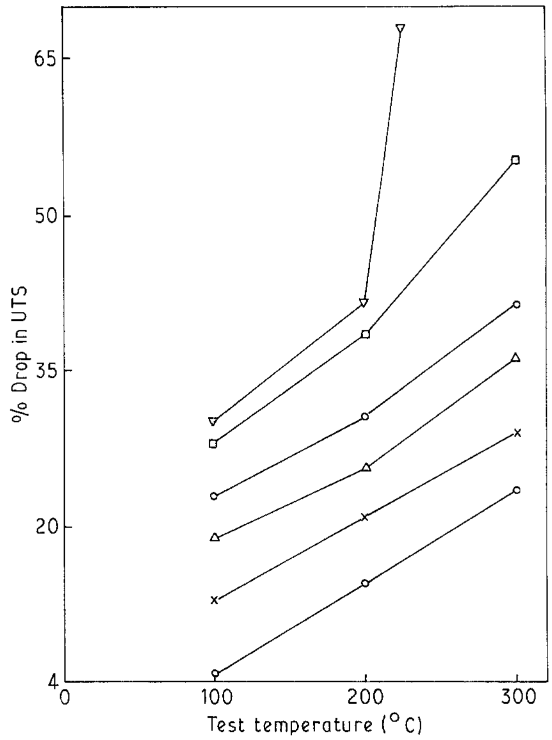


Figure 8 Per cent drop in UTS obtained in (▽) commercially pure aluminium, (□) gravity chill-cast and (○, △, ×, ●) squeezed composites (ambient die temperature) shown as a function of the three test temperatures, and at (○) 80 MPa, (△) 100 MPa, (×) 120 MPa, (●) 140 MPa.

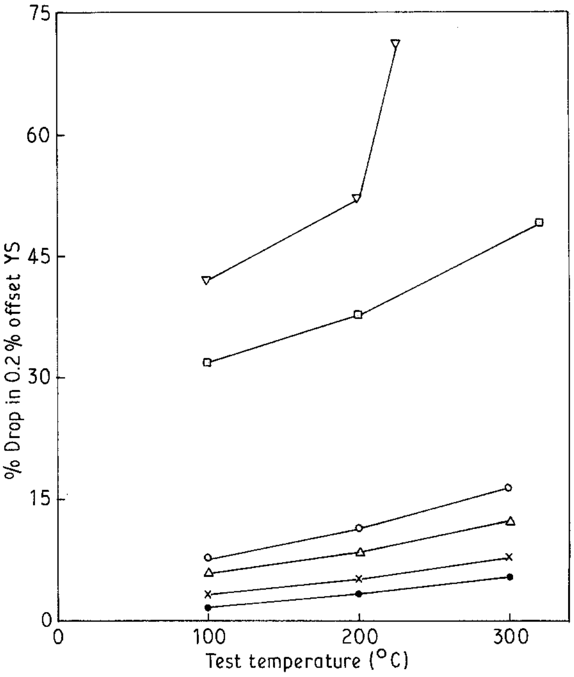


Figure 9 Per cent drop in 0.2% offset YS obtained in (▽) commercially pure aluminium, (□) gravity chill-cast and (○, △, ×, ●) squeezed composites (ambient die temperature) shown as a function of the three test temperatures, and at (○) 80 MPa, (△) 100 MPa, (×) 120 MPa, (●) 140 MPa.

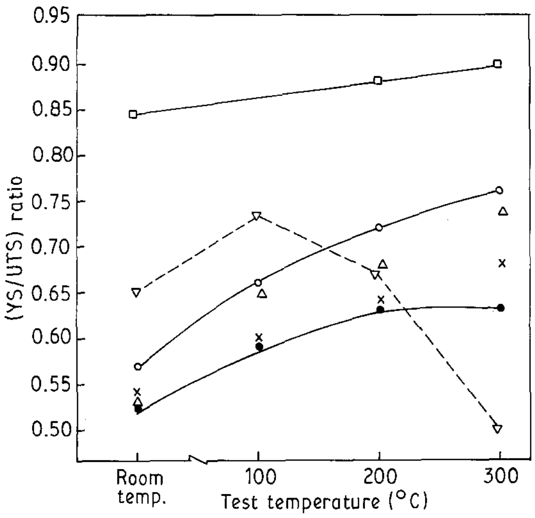


Figure 10 Relationship between YS/UTS ratio and the three different test temperatures obtained for (▽) commercially pure aluminium, (□) gravity chill-cast and (○, △, ×, ●) squeezed composites (ambient die temperature), at (○) 80 MPa, (△) 100 MPa, (×) 120 MPa, (●) 140 MPa.

160–240 MPa. This improvement in the tensile behaviour of squeezed composites can be directly attributed to (a) the virtual absence of porosity due to a high level of densification achieved, and (b) an increasing degree of grain refinement obtained upon squeezing. The role of coarser Al_2O_3 particles and submicrometre MgO particles in stiffening the aluminium-base matrix has been discussed in detail in earlier publications [3–5]. The above strengthening mechanism results in improved tensile properties of the composite at elevated temperatures. Also, it can be seen from the data recorded in Table I that increasing degree of grain refinement obtained upon squeezing has a profound effect on the tensile behaviour of the composites.

The performance of the composites with regard to 0.2% off-set YS values is of prime interest as this is the basic design criterion employed in actual practice. It can be seen that the 0.2% offset YS value of the best composite prepared in this work (140 MPa and ambient die temperature) is higher by ~53% compared to the value of gravity chill-cast composite at 100 °C (373 K) test temperature. These values progressively magnify to 88.5% and 105% at 200 °C (473 K) and 300 °C (573 K) test temperatures, respectively. This is basically because the squeezed composite retains its YS better than simple gravity chill-cast composites at elevated temperatures. For example, the squeezed composite referred to above, retains 94.4% of its ambient YS value at 300 °C (573 K) test temperature, while ordinary gravity chill-cast composite retains only 47.6% of its ambient YS value at the same test temperature. It is, therefore, apparent that the performance of squeezed composites is far superior to ordinary gravity chill-cast composites.

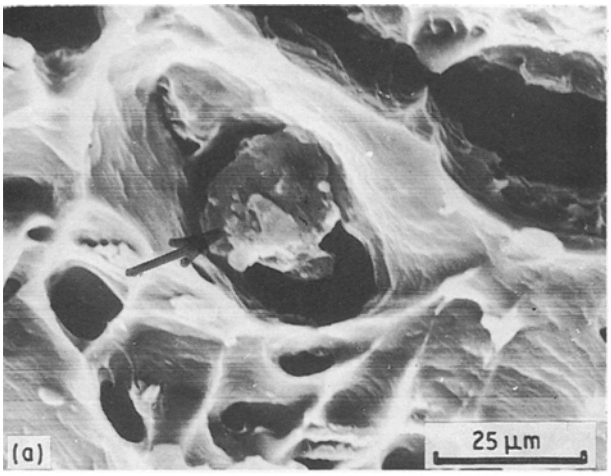
The basic aspect of loss of strength of different materials at elevated temperatures is compared in Figs 8 and 9. It should be noted that the rate of loss of strength for commercially pure aluminium and gravity chill-cast composites becomes fairly steep between 200 and 300 °C test temperatures. Particularly for pure aluminium, the tensile tests could not be conducted beyond 225 °C (498 K) because this material lost strength very rapidly beyond 200 °C. This rate of loss of strength beyond 200 °C tapers off gradually as the squeeze pressure is progressively raised. It can be seen that the overall behaviour pattern of loss of strength between 100 and 300 °C test temperatures is practically linear in case of composites squeezed at 120 and 140 MPa. Moreover, the overall loss of strength (UTS) progressively decreases as the squeeze pressure is systematically raised in steps. It should, therefore, be logically possible to improve the performance of the composite even further if the squeeze pressure is taken to still higher levels, such as 160–240 MPa. Work in this direction is underway and the results will be reported in the near future.

While referring to Fig. 9, it can be seen that the performance of squeezed composites is distinctly different and superior to ordinary gravity chill-cast composite. Also, among the group of squeezed composites, the best performance is displayed by the composites squeezed at 120 and 140 MPa. Apparently, the composites squeezed at 140 MPa can be put to practical applications up to 300 °C (573 K) with fairly good assurance of performance reliability. The elongation data plotted in Figs 6 and 7 show entirely expected results.

The YS/UTS ratio plotted in Fig. 10 as a function of test temperatures is indicative of much superior performance of squeezed composites compared to ordinary gravity chill-cast composites. The objective of this plot is to show that squeezed composites retain their 0.2% offset YS better than ordinary gravity chill-cast composites at elevated test temperatures. The YS/UTS ratio is higher for gravity chill-cast composites primarily because they undergo premature failure in tension due to the presence of voids in the cast structure [10–13]. This implies that such composites do not develop the expected UTS values in actual practice and therefore their YS/UTS ratio is on the higher side. On the other hand, this ratio drops sharply in case of commercially pure aluminium with increasing test temperature, which would be entirely expected.

3.4. SEM examination of tensile fracture surfaces

Scanning electron micrographs of the tensile fracture surface of the composite squeezed at 140 MPa and ambient die temperature and tested at 100 °C (373 K) are shown in Fig. 11a and b. The fracture surface can be seen punctuated by numerous deep dimples indicative of fully ductile mode of fracture. Deformation markings along the walls of individual craters can also be clearly seen. The individual dimples appear to be fairly deep which indicates that the matrix was pulled to a long distance before final fracture. Also, individual dimples can be seen to be separated from each other by a thin edge of base matrix at the point of final separation. This thin edge or chisel point separation of dimples is indicative of the high level of ductility of



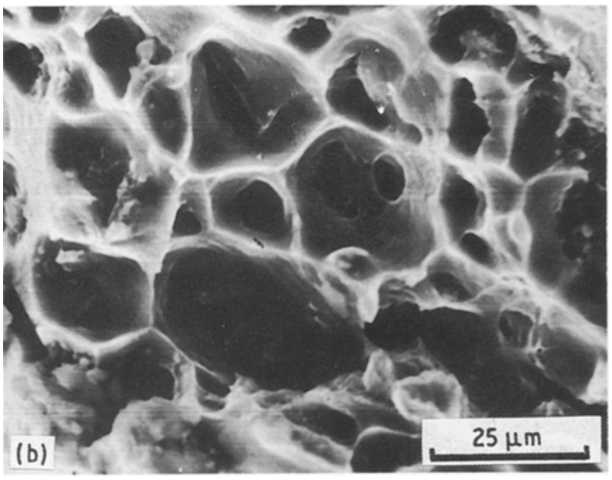


Figure 11 Scanning electron micrographs of the tensile fracture surfaces of (a) the composite squeezed at 140 MPa and ambient die temperature and (b) pulled in tension at 100 °C (373 K).

the base matrix. Apparently in the present case, the final fracture has occurred through coalescence of voids. Such a process of void formation through particle–matrix decohesion at the surface of Al_2O_3 particles is seen in Fig. 11a marked by an arrow (note the Al_2O_3 particle sitting at the base of a crater). It is also interesting to note that in some instances, one larger dimple is surrounded by several smaller dimples (Fig. 11a).

The present composite contains dispersions of Al_2O_3 particles with a wide spectrum of size range (53–150 µm). It is because of this reason that the size of the dimples is non-uniform. The ductile fracture features of squeezed composites observed at all the test temperatures is indirectly supported by the per cent elongation data recorded in an individual case (Table I). It should also be mentioned that porosity or unfed interdendritic regions were not found in such composites, as observed earlier in gravity chill-cast composites [10]. Increasing the test temperature does not bring about any basic change in the mode of fracture, except that the average size of dimples progressively increases. This particular feature was noted by other investigators also involving a slightly different composite system [8].

4. Conclusions

1. Squeezing the stirred slurry in the pressure range 80–140 MPa brings about a distinct improvement in the elevated temperature tensile properties of the composite. The best properties are displayed by a composite squeezed at 140 MPa and ambient die temperature. Increasing the die temperature systematically deteriorates the properties.

2. The UTS of the composite squeezed at 140 MPa and ambient die temperature is higher by 52% at 100 °C (373 K) test temperature compared to ordinary gravity chill-cast composite. This figure improves to 161% and 162% at 200 °C (473 K) and 300 °C (573 K) test temperatures, respectively. This implies that the above composite retains about 77% of its ambient UTS value at 573 K test temperature, while the gravity chill-cast composite retains only 44% of its ambient UTS value at the same test temperature. The same squeezed composite retains 160.4 $MN\,m^{-2}$ UTS value at 300 °C, while the gravity chill-cast composite retains only 61.1 $MN\,m^{-2}$ UTS at the same test temperature.

3. Results pertaining to 0.2% offset YS values of the squeezed composite at different test temperatures are more encouraging. The squeezed composite (140 MPa and ambient die temperature) retains 94.4% of its ambient YS value at 300 °C (573 K) test temperature, while the gravity chill-cast composite retains only 47.6% of its ambient YS value at the same test temperature. The YS of the same squeezed composite is higher by 105% compared to the YS value of gravity chill-cast composite at 300 °C (573 K) test temperature. At 100 °C test temperature, the squeezed composite is superior by 53% compared to gravity chill-cast composite. Therefore, with progressive increase in test temperature, the performance of the squeezed composite becomes increasingly superior to ordinary gravity chill-cast composite.

4. With further increase in the squeeze pressure applied, such as 160–240 MPa, the performance of the composite is likely to improve further.

5. Squeezed composites show fully ductile fracture features. No evidence of the presence of porosity and interdendritic unfed regions in the squeeze-cast composites was observed.

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