High strength aluminium alloys constitute the bulk of the aircraft structural materials and hence attempts to improve their properties like strength, corrosion resistance, fracture toughness and fatigue crack propagation rates have been going on since long. These are mainly concerned with adjustment in alloy composition to improve the strength by increasing the volume fraction of the precipitating phases, reducing the limits of impurities like Fe and Si which form coarse insoluble intermetallic compounds and thermomechanical treatments. However, such attempts have been found to result in only a marginal improvement in properties though considerably increasing the costs. Hence, alternate processing routes like use of atomized powders have been investigated as early as 1961, by Towner who showed that the Al-8% Fe alloy, when processed from sintered aluminium product (SAP). Skelly and Dioxide showed that by using powder metallurgical processing hyper-eutectic Al-35% Si alloy having better mechanical, thermal expansion and wear properties could be produced. Following the early work of Towner, Harr and Lyle and Cebulak showed that Al–Zn–Mg–Cu alloys containing Fe and Ni or Co, produced from atomized powders exhibit better strength and stress corrosion resistance than when produced from ingots. This is due to the presence of Fe, Ni or Co in the form of fine dispersions, as well as to the fine grain-size of the atomized powder solidified at cooling rates of about 10³ K/s. The advent of splat cooling technique capable achieving cooling rates of 10⁶ K/s and above, gave an impetus to the development of newer rapid solidification techniques like melt spinning, twin roller quenching, centrifugal atomization etc., for bulk production of rapidly solidified alloys and led to the investigation of the impact of such high cooling rates on the properties of alloys. Rao et al. obtained spectacular improvement in the properties of Al–Ni and Al–Si alloys.

In one of the earliest investigations of rapid solidification processing (RSP) of high strength Al alloy Mobley et al. processed commercial 7075 alloy by melt spinning. The as spun alloy was converted into rods by adopting powder metallurgical steps of cold compaction and vacuum annealing followed by hot compaction to get billets of about 85% of theoretical density. The billets were enclosed in aluminium cans and extruded at 350°C with an extrusion ratio 36:1. The heat treated (T₆) alloy was found to exhibit a moderate (10%) increase in room temperature yield strength than the ingot processed alloy. However, at 400°C, the RSP alloy was found to exhibit super-plastic properties. The improvement in properties of the RSP alloy was attributed to the presence of about 1 vol% Al₂O₃ and the extremely fine grain size. Later Durand et al. employed the twin roller technique to process commercial 7075 alloy as well as the modified with addition of Fe (0.6%) and Ni (1.0%). The modified alloy was found to exhibit about 25% improvement in the mechanical properties compared to the ingot processed 7075 alloy. However, they encountered axial cracking in the alloys due to the concentration of Al₂O₃ particles in the form of stringers. Using ultrasonic gas
atomization process Anand and Kaufman\textsuperscript{12} could get only a marginal improvement in the properties. However, Domalavage et al.\textsuperscript{13} could get a significant improvement in properties of 7075 alloy containing Ni (1.1%) and Zr (0.8%) processed from ultrasonic gas atomized powders. The RSP alloy exhibited more than 70\% improvement in fatigue life compared to commercial 7075 alloy. However, the RSP alloy suffered from delaminations along the axially aligned oxide stringers suggesting that additional deformation subsequent to extrusion is necessary for improving the properties. Further details of the microstructures and properties of RSP aluminium alloys can be found in the review by Lavernia et al.\textsuperscript{14} and elsewhere\textsuperscript{5-7}. In USA the RSP aluminium alloys are being evaluated by aircraft companies for replacing the ingot processed alloys in some applications. In this paper, the microstructure and mechanical properties of 7075 type high strength aluminium alloys produced from rapidly solidified platelets have been presented.

**Experimental Procedure**

The composition (wt\%) of various Al–Zn–Mg–Cu alloys studied in this investigation are given in Table 1. The alloys were prepared from metals of commercial purity in an electrical resistance furnace using sodium free fluxes. Appropriate master alloys containing 5 wt\% TM (transition metal) were used for adding Fe, Mn and Ni.

Rapid solidification of alloys was carried out using a centrifugal atomization and rapid quenching set-up is shown in Fig. 1. It consists of an electrically heated holding furnace having a graphite crucible. The crucible was fitted at the bottom with a graphite nozzle of 2 mm diameter to allow the molten metal flow in a thin stream. Atomization of the alloy was achieved by means of a preheated, rotating graphite disc fitted to the shaft of a motor rotating at 1000 rpm and located directly below the nozzle of the holding crucible. Rapid solidification was achieved with the help of a circumferential aluminium substrate, cooled by water spray. The droplets travelling radially at high velocity strike the substrate and spread into thin discs or platelets and solidify rapidly. In the present study, the temperature of the holding furnace was kept at 800\degree C and the alloy was poured into the crucible with about 100-150\degree C superheat. With the experimental set-up about 3 kg of alloy could be rapidly solidified in about 5 min. Platelets of 3-5 mm dia were separated from the rest, with the help of screens for further processing. The platelets were then made into compacts of about 75 mm diameter and about 25 mm height with a pressure of 100 kg/mm\textsuperscript{2} in a hydraulic press. By this method green compacts with 75\% of theoretical density could be produced. The compacts were then heated at 400\degree C for 6 h and cooled to room temperature under a vacuum of 10\textsuperscript{-3} torr. The compacts were then extruded at 300\degree C into rods of 12 mm diameter, with an extrusion ratio of 36:1. The extruded rods were heat treated to the T6 condition, i.e., solution treatment at 460\degree C for 1 h, water quenching and ageing at 120\degree C for 24 h.

Microstructure of the rapidly solidified platelets was examined with an optical microscope. The substrate side of the platelets could be examined without any surface preparation. The longitudinal and transverse sections of the extruded rods were examined after conventional polishing and etching. Tensile properties of the extruded rods were

![Fig. 1 — Schematic diagram of the rapid solidification set-up](image)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Zn%</th>
<th>Mg%</th>
<th>Cu%</th>
<th>Fe%</th>
<th>Mn%</th>
<th>Ni%</th>
<th>Al%</th>
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</thead>
<tbody>
<tr>
<td>7075-A</td>
<td>5.6</td>
<td>2.5</td>
<td>1.5</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Balance</td>
</tr>
<tr>
<td>AF</td>
<td>5.6</td>
<td>2.5</td>
<td>1.5</td>
<td>1.0</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>AM</td>
<td>5.6</td>
<td>2.5</td>
<td>1.5</td>
<td>—</td>
<td>1.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>AN</td>
<td>5.6</td>
<td>2.5</td>
<td>1.5</td>
<td>—</td>
<td>—</td>
<td>1.0</td>
<td>—</td>
</tr>
</tbody>
</table>
determined with the help of a Hounsfield tensometer. The values reported are the average of three tests.

Results and Discussion

The average size of the rapidly solidified platelets was 3-5 mm in diameter and 0.02-0.05 mm in thickness. About 20% of the platelets were found to be of larger size.

The microstructure of the platelets, the substrate side and along the cross-section, of all the alloys consisted of dendritic grains, as shown in Fig. 2. The secondary dendrite arm spacing was in the range of 1-1.5 μm indicating the cooling rate to be in the range of $10^4$-$10^5$ °C/s. It may be noted that in all rapid solidification studies normally a copper substrate is used on account of its high thermal conductivity. In this investigation, in spite of using an aluminium substrate having a lower thermal conductivity than copper, the cooling rates achieved have been high. This may be attributed to the intimate thermal contact achieved due to the high velocity impact of the droplets on the substrate. The grain size was found to be quite non-uniform. Often elongated grains, dendrite remelting resulting in spherical morphology and in somewhat thicker areas of the foils, fine cellular structures were also observed, as shown in Fig. 2 and discussed earlier. These observations are in keeping with the well-established theories of microstructure formation. An interesting observation made in the platelets of alloy AM was the occurrence of grains exhibiting spiral morphology, as shown in Fig. 3a. Such growth spirals had been observed in crystals. Frank suggested that crystal growth could be aided by a screw dislocation emerging on the growing surface of a crystal, due to the introduction of a perpetual step. When a crystal is growing, the growth rate is influenced not only by the driving force, i.e., undercooling or super saturation but also by the nature of the solid liquid interface. If the interface is rough then crystal growth would be easy and the growth rate would be proportional to the driving force, undercooling $\Delta T$, and known as continuous growth. If the interface is a close packed plane and smooth, then crystal growth will occur by repeated nucleation and lateral growth of layers (steps) and

![Fig. 2 - Microstructure of rapidly solidified 7075 type alloys exhibiting (a&b) dendritic, (c) cellular and (d) spherical morphology due to dendritic remelting.](image-url)
hence crystal growth can occur only when the driving force exceeds some threshold value. However, if a screw dislocation is emerging on the growing surface it introduces a perpetual step on the growing surface and results in the spiralling of the atomic planes. Now crystal growth can occur by the addition of atoms to the step without repeated nucleation. This mechanism of crystal growth is important for small undercoolings and has been observed in several inorganic crystals. Other details of the crystal growth mechanisms can be found in standard texts on physical metallurgy and solidification. In case of metals which solidify by continuous growth, the screw dislocation mechanism is not important. In rapidly solidified alloys dislocation aided growth has not been previously reported. According to Frank, the initial dislocation due to growth on a foreign solid which might be dislocated already or due to very high supersaturation, or deformation of the initial crystal by impurities. In the present experiments, the use of an aluminium substrate having the same crystal structure and almost the same lattice parameter as the alloy crystal and also the large supersaturation might have both contributed to the formation of the initial dislocation, and hence the spiral morphology.

Sometimes in some of the platelets a duplex microstructure was observed (Fig. 3b). This is attributed to the start of solidification in the droplet even before it hit the substrate. It was found that a melt superheat, of 100°C was necessary for the smooth flow of the molten metal through the nozzle and also to prevent the solidification of the droplets while in flight. The microstructure of the extruded rods of all alloys consisted of a fine dispersion of precipitates, formed during the various stages of processing, in the aluminium matrix (Fig. 4). The Al–Zn–Mg–Cu alloys develop the best properties in the fully heat treated (T6) condition. This will result in the formation of coherent G.P. Zones in the aluminium matrix. In the alloys containing the transition elements the intermetallic compounds formed will be present in the form of fine dispersoids. In addition the RSP alloys contain about 1 vol% Al2O3 in the form of fine particles. The mechanical

![Image](image1.png)

**Fig. 3** — Microstructure of rapidly solidified alloy exhibiting (a) spiral morphology originating from screw dislocations and (b) bi-modal morphology

![Image](image2.png)

**Fig. 4** — Microstructure of RSP high strength aluminium alloys in the as extruded condition (a) longitudinal and (b) in the transverse directions showing fine and uniform distribution of second phase of particles
Table 2 — Mechanical properties of the experimental RSP alloys in fully aged (T6) condition

<table>
<thead>
<tr>
<th>Alloy code</th>
<th>VHN kg/mm²</th>
<th>UTS kg/mm²</th>
<th>%EL</th>
<th>%RA</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>A</td>
<td>160</td>
<td>58</td>
<td>11</td>
<td></td>
<td>Commercial</td>
</tr>
<tr>
<td>A</td>
<td>154</td>
<td>59</td>
<td>10</td>
<td></td>
<td>Ductile Fracture</td>
</tr>
<tr>
<td>AF</td>
<td>162</td>
<td>62</td>
<td>9</td>
<td></td>
<td>Ductile Fracture</td>
</tr>
<tr>
<td>AM</td>
<td>165</td>
<td>56/60</td>
<td></td>
<td></td>
<td>Fibrous Pullout</td>
</tr>
<tr>
<td>AN</td>
<td>172</td>
<td>64</td>
<td>8</td>
<td>6</td>
<td>Ductile Fracture</td>
</tr>
</tbody>
</table>

properties of the experimental alloys are given in Table 2. It is clear from the table that the mechanical properties of the 7075 alloy improve only marginally when subjected to RSP, as also reported. Addition of 1.0 wt% of transition elements to the 7075 alloy improves the mechanical properties further due to the formation of fine particles of the intermetallic compounds. All the alloys, except AM, exhibited good ductile fracture. The manganese containing alloy failed by fibrous pull out as shown in Fig. 5. This is due to some what higher superheat employed (melting temperature of 800-850°C) during rapid solidification, and consequent greater oxidation of the platelets which precludes good bonding.

The various stages of RSP, platelets, compacts and extruded rods are shown in Fig. 6. A noteworthy feature of the present work is that the compacts of the RS alloys were not sealed in aluminium cans before
extrusion, as practiced by other investigators\textsuperscript{10-14}. In spite of that a good consolidation and surface finish in the extruded alloys could be achieved.

Conclusions

The following conclusions can be drawn from the present study.

(i) High cooling rates, of the order of $10^4$-$10^5$ °C/s could be achieved even with the use of an aluminium substrate.

(ii) Good consolidation and surface finish could be obtained in the extruded alloys even without canning.

(iii) RSP results in only a moderate improvement in properties of commercial alloys.

(iv) Addition of transition elements increases the mechanical properties of the high strength aluminium alloys subjected to RSP.

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