Extremely high strength aluminium alloys have been developed in the laboratory, in recent times. However, most of them refer to either fully amorphous or partially amorphous alloys. Though some of these alloys display strengths as high as 1500 MPa at ambient temperatures, their stability deteriorates at higher operating temperatures due to coarsening. This deficiency can be overcome if the processing route is tailored to directly synthesise a nanocrystalline microstructure consisting of a large fraction of finely dispersed intermetallic phases in a single step process, without altering the original alloy composition too much and without going via a two step annealing process. The presence of more than one type of intermetallic phase can inhibit coarsening more effectively and also help attain higher strengths. The overall effect will be even more pronounced if the starting sizes of the matrix grains are themselves fine to begin with, and if the alloying additions forming the intermetallic phase exhibit limited solubility and diffusivity in the solid state.

It is now well established that fine grain sizes are a pre-requisite for enhanced properties. There are several ways of achieving a reduction in sizes of the alloy microstructures. Amongst all those methods rapid solidification has evolved as a powerful technique to arrive at nanocrystalline structures. The addition of minor amounts of transition metal elements has been found to inhibit grain growth and impart good strength to the alloy. This is because of both, a limited solubility that they exhibit in Al, and their propensity to form intermetallic compounds with Al. There have not been many reports of studies on nanosized microstructures synthesised via a single step process, and even the few that exist have not dealt with the stability and mechanical properties of these alloys.

The present study examines the feasibility of synthesising fine grained Al alloys with a large fraction of intermetallic phases, directly from the liquid in a single step process. A compositional window has been demarcated by a careful examination of the alloy design considerations for achieving such microstructures, based on already existing literature. A series of ternary alloys have been processed based on the binary eutectics of Al-X (X=Si,Cu,Ni), with Zr additions of 3 at%. The core of this thesis consists of two main parts and has been arranged into Chapter 3 and 4. The first portion deals with the synthesis and stability of nanocrystalline microstructures, while the second part analyses the possible
strengthening mechanisms that could be operative, in such multiphase fine grained materials

Chapter 3 comprises all the principal observations on the microstructural evolution in all the three alloy systems. It has been established that nanocrystalline microstructures can be synthesised in three different Al based systems, via the melt spinning technique. The stability ranges of all these microstructures have been examined and demarcated, by annealing at different temperatures and times, and by monitoring the phase transformations and coarsening that takes place, via microhardness measurements. The non-equilibrium nature of the processing route enables the formation of phases that have otherwise not been predicted in the equilibrium phase diagram.

Two metastable phases have been observed in the Al-Si-Zr series. One was seen on solidification, while the other metastable phase, forms after annealing. The former is identified as a high temperature ternary ordered phase \(\tau_1\), having a \(\text{DO}_{22}\) structure. The latter has been identified to have a crystal structure related to the equilibrium orthorhombic \(\text{Si}_2\text{Zr}\). While the as-solidified phase can be classified as being compositionally metastable, the phase on annealing would come under a structural metastability. Detailed analysis of the phase identification, solidification path and crystallography rationalising their formation, has been carried out.

Following the Al-Si-Zr series, are alloys belonging to the Al-Cu-Zr series. The emphasis here lies in the achievement of a truly nanocomposite two phase microstructure in the as-solidified, near-eutectic alloy, \(\text{Al}_{82}\text{Cu}_{15}\text{Zr}_3\). A very high hardness has been correlated with this microstructure which comprises ~25 nm sized grains of both, \(\alpha\)-Al and intermetallic \(\text{Al}_2\text{Cu}\) phases, occurring together. The solidification path enabling the synthesis of this type of microstructure is attributed to a high nucleation rate of the two competing eutectic phases during rapid quenching. The highlighting feature of the next series (Al-Ni-Zr), was in the formation of two different morphologies of the primary metastable \(\text{L}_1_2\)-Al\(_3\)Zr phase, in the two alloys in this series, and its subsequent transformation on annealing. While the Al rich composition had this phase with a distinct two phase duplex appearance, the alloy away from the Al end had single phase primary particles. The former was seen to dissolve and reprecipitate as the same phase, under the constraint imposed by migrating Al boundaries, during annealing.

Having synthesised these nanocrystalline alloys, a study of their mechanical behaviour has been carried out using hardness measurements (Chapter 4). All the ternary alloys studied in
This thesis were found to exhibit very high values of hardness going up to 5 GPa. Several mechanisms tend to operate in tandem in such multi-phase, multi-component, fine grained materials. The different mechanisms responsible for strengthening have been examined in each case, via an analysis of their hardness. The role played by ternary Zr additions on the different binary eutectic alloys is also brought out via this analysis. It has been concluded that the impact due to grain refinement is the strongest. Nevertheless, this grain size effect is not a singular one, and is found to be substantially supplemented by the role played by the grain boundary precipitates.

Finally, in Chapter 5 the overall implication of generating such alloy microstructures is discussed, with special emphasis on the role played by transition metal additions such as Zr. The salient conclusions of the entire study are summarised in this chapter. In summary, this thesis presents a study on the microstructural evolution, crystallographic analysis, thermal stability and strengthening mechanisms of a series of nanocrystalline Al alloys with a high fraction of intermetallic phases, generated using rapid solidification in conjunction with ternary transition metal Zr additions. The attempt at estimating the relative contributions to the strength is not so specific to these alloys and can be extended to the whole class of nanocrystalline multiphase materials.