Electron microscopy of metastable phases in rapidly solidified Al–Co alloys[†]

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Abstract. Four binary Al–Co alloys containing 2.4, 14, 20 and 25 at.%Co and a ternary Al–Co–Si alloy with 20 at.%Co and 5 at.%Si were rapidly solidified from the liquid state by melt spinning. It has been shown that the solid solubility of Co in Al can be increased up to at least 1.7 at.% from the negligible value under equilibrium conditions. Two metastable crystalline intermediate phases and a D1_a-type ordered phase were observed in localized regions in the rapidly solidified Al–2.4 at.%Co alloy. A quasicrystalline decagonal phase has been observed in all the other rapidly solidified alloys. This decagonal phase was shown to contain dislocations, dislocation loops and also twin-like defects. The phenomenon of polytypism was also observed in this decagonal quasicrystalline phase. In extremely thin areas of the Al–14 at.%Co alloy ribbons an amorphous phase was detected. Transmission electron microscopy was used to extensively characterize the phases in the as-solidified condition and also those produced during and after transformation to the equilibrium constitution.

Keywords. Al–Co alloys; transmission electron microscopy; rapid solidification; supersaturated solid solutions; metastable intermediate phases; decagonal quasicrystalline phase; polytypism; amorphous phase; transformation studies.

1. Introduction

Rapid solidification of metallic melts at rates $> 10^5$ K/s has been employed since 1960 to produce metastable effects in alloy systems. The pioneering efforts of Duwez *et al* (1960a) on rapid solidification led to the synthesis of supersaturated solid solutions, metastable crystalline intermediate phases (Duwez *et al* 1960b), and at sufficiently high cooling rates even metallic glasses (Klement *et al* 1960) in a variety of alloy systems. This rapid solidification technology (RST) has now developed from a relatively insignificant activity into a major field of metallurgical study in just about 25 years. Eight international conferences (devoted exclusively to a study of rapidly quenched metals), several national and regional conferences, and well over 25,000 research publications testify to the continued exponential growth of activity in this exciting area. A further fillip to this field was given with the report by Shechtman *et al* (1984) that electron diffraction patterns from rapidly solidified Al–14 at.% Mn alloys (all compositions in this paper are expressed in atomic percent unless otherwise mentioned) exhibit the crystallographically forbidden five-fold symmetry. All the metastable effects referred to above, coupled with the observation that significant refinement in grain

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Table 1. Crystal structure data of the equilibrium intermediate phases in the Al–Co system (Villars and Calvert 1991; Ma and Kuo 1992).

Phase	Pearson symbol	Space group	Lattice parameters			
			<i>a</i> (nm)	<i>b</i> (nm)	<i>c</i> (nm)	β or <i>c/a</i>
Al ₉ Co ₂	mP22	P2 ₁ /c	1.0149	0.6290	0.8557	94.76°
Al ₁₃ Co ₄	mC102	Cm	1.5183	0.8122	1.2340	107.9°
τ^2 -Al ₁₃ Co ₄	—	Cm	3.98	0.81	3.22	108°
	—	Pm	3.98	0.81	3.22	108°
Al ₃ Co	o*	Pnmm	1.25	0.81	1.46	1.168
Al ₅ Co ₂	hP28	P6 ₃ /mmc	0.7656		0.7593	0.992
AlCo	cP2	Pm $\bar{3}$ m	0.2862	—	—	—

sizes and segregation patterns take place in these alloys, have aided in developing new alloy chemistries and improved combinations of properties by extended alloying and/or novel processing techniques. These efforts have been summarized in several publications (see, for example, Suryanarayana 1980a; Güntherodt and Beck 1981; Jones 1982; Beck and Güntherodt 1983; Cahn 1983; Luborsky 1983; Anantharaman 1984; Das *et al* 1985; Gratias and Michel 1986; Anantharaman and Suryanarayana 1987; Suryanarayana and Jones 1988; Kelton 1993; Liebermann 1993).

It has been reported that any alloy system subjected to rapid solidification exhibits one or more of the above effects, but generally not all of them. However, in the Al–Co system we have been successful in achieving grain refinement and synthesis of all the metastable phases (supersaturated solid solutions, crystalline and quasicrystalline intermediate phases, and amorphous phases). The role of transmission electron microscopy in characterizing the as-solidified structures as well as their transformation to the equilibrium phases will be described in this paper.

The solid solubility of cobalt in aluminium under equilibrium conditions is < 0.01% (< 0.02 wt%) at the eutectic temperature of 930 K and virtually nil at room temperature (Mondolfo 1976). A large number of intermetallic phases have been found to form in this system. Their crystal structure data are listed in table 1 (Pearson 1967; Villars and Calvert 1991). The intermediate phase richest in aluminium has a stoichiometry of Al₉Co₂ and a monoclinic crystal structure with *a* = 1.0149, *b* = 0.6290, *c* = 0.8557 nm and β = 94.76° (Villars and Calvert 1991).

2. Experimental procedure

Four binary Al–Co alloys containing 2.4, 14, 20 and 25% Co were prepared from high-purity constituent elements in an arc-melting furnace under a protective argon atmosphere. In addition, a ternary Al–Co–Si alloy containing 20% Co and 5% Si was prepared in a similar manner to study the effect of addition of a ternary element on the formation and transformation behaviour of the metastable phases. These alloys were repeatedly remelted and homogenized. Rapid solidification from the melt was carried out by the technique of melt spinning. In this method, the melt was ejected through a fine orifice in a silica crucible on to a copper wheel of 20 cm diameter rotating at about 3000 rpm. Ribbons, a few mm in width, and having regions thin

enough for direct transmission electron microscopic examination, were obtained. Some of the foils were heat-treated in evacuated silica tubes at different temperatures and for different lengths of time to follow the transformation behaviour of the metastable phases to the equilibrium state. *In-situ* hot-stage electron microscopy was also carried out on some foils. Bright-field, dark-field, diffraction and lattice resolution modes were extensively used to characterize the as-quenched as well as heat-treated foils in a JEOL JEM-200 CX transmission electron microscope operating at 200 kV and fitted with a goniometer stage. A KEVEX energy dispersive X-ray detector was used for microanalysis of the various phases obtained.

3. Results and discussion

The results obtained on the four binary alloys and one ternary alloy in the as-quenched condition and the behaviour of the transformation of the metastable phases to their equilibrium counterparts will be presented under three major categories, viz. microcrystalline, quasicrystalline and amorphous phases.

3.1 Microcrystalline phases

In the melt-spun Al-2.4%Co alloy, a variety of microstructures could be obtained depending on the thickness of the foil (and hence the cooling rate). Although in extremely thin areas a completely supersaturated solid solution formed, e.g. in gun-quenched foils (Hanumantha Rao *et al* 1987), most commonly a two-phase structure was observed, and typical microstructures are presented in figure 1. While the second phase is very finely dispersed inside the elongated grains in figure 1a, it is mostly occurring along the interdendritic boundaries in figure 1b. At lower cooling rates, the second phase is present in the form of massive particles (figure 1c). A common feature of all these micrographs is that the grain size is typically $< 1 \mu\text{m}$, suggesting that in comparison to the as-cast structure, a grain refinement by about two orders of magnitude occurred in the rapidly solidified condition. A typical electron diffraction pattern obtained from the two-phase as-rapidly solidified structure is shown in figure 1d. The two phases could be unambiguously identified as f.c.c. α -Al and monoclinic Al_9Co_2 .

From the above it becomes clear that with decreasing cooling rate the constitution of the as-solidified alloy can be described as consisting of supersaturated solid solution $\rightarrow$ fine dendrites $\rightarrow$ coarse dendrites $\rightarrow$ mixture of slightly supersaturated solid solution and massive Al_9Co_2 particles. Occasionally, one could also observe the massive particles distributed in some geometric shapes and their density also has been found to be high. Irrespective of the density, size and shape, these particles were unambiguously identified as belonging to the Al_9Co_2 phase (Menon and Suryanarayana 1988a). These observations are consistent with those reported earlier by Garrett and Sanders (1983) and Sater *et al* (1986). X-ray microanalysis of the as-quenched alloy indicated that the solid solution contains about 1.7% Co, while the Al_9Co_2 contains about 13% Co.

Although the above described effects were observed in all the foils, in highly localized regions it was possible to detect the presence of D1_a -type ordering corresponding to a hypothetical Al_4Co composition (Van Tendeloo *et al* 1987). In addition to diffraction

Figure 1. Typical microstructures from electron-transparent thin portions of the melt-spun Al-2.4%Co alloy ribbon. The second-phase particles are very finely and uniformly distributed (a) inside the elongated grains or (b) in the interdendritic regions. (c) Distribution of massive Al₃Co₂ intermetallic particles, (d) a typical diffraction pattern from the as-melt spun ribbon indicating the presence of α -Al and Al₃Co₂ phases.

effects, high-resolution electron microscopy evidence could be obtained to confirm this observation.

In some regions of the foils, however, a different constitution could be observed. For example, a b.c.c. phase with $a = 0.286$ nm (corresponding to the β -AlCo phase) was found to be present in a metastable condition in the interior of the cells of the cellular-dendritic structure. Another metastable f.c.c. phase with $a = 0.52$ nm could also be detected occasionally. Occurrence of these metastable phases in the as-quenched condition can be rationalized if one realizes that clustering of solute atoms can take place even during the quenching operation (Fontaine and Guinier 1976). This can lead to solute-rich and solute-lean regions and hence metastable phases of widely different compositions can co-exist in the alloy. Furthermore, from the binary Al-Co equilibrium diagram it can be noted that all the intermediate phases (except β -AlCo) in the Al-Co system are formed as a result of peritectic reactions, which are known to be sluggish in nature. Therefore, it is easy to explain the formation of the β -AlCo phase in a metastable state in a very dilute Al-2.4%Co alloy if one assumes that formation of all other phases (Al₃Co₂, Al₁₃Co₄ and Al₅Co₂) is suppressed due to kinetic constraints, essentially because of the drastic undercooling experienced by the liquid during rapid solidification. Rearrangement of the Al and Co atoms in the

Figure 2. Transformation behaviour of the melt-spun Al-2.4%Co alloy foils with massive intermetallic particles: (a) annealed at 573 K showing “pinching off” of particles in the cell boundaries, (b) annealed at 673 K showing coarsening of these particles, and (c) annealed at 773 K at which stage all particles aggregate and assume faceted or nearly spherical shapes.

Figure 3. Transformation behaviour of the melt-spun Al-2.4%Co alloy foils without massive particles: (a) relatively thinner foil annealed at 573 K showing slight coarsening of the precipitate along the interdendritic boundaries, (b) annealed at 673 K showing coarsening of the Widmanstätten plates formed at 623 K and (c) presence of interfacial dislocations due to the strain between the matrix and the precipitates.

β phase can result in the formation of the f.c.c. metastable phase as discussed earlier (Menon and Suryanarayana 1988a).

The behaviour of the transformation of the supersaturated solid solution to the equilibrium phases was found to be slightly different depending on whether the as-quenched alloy contained massive particles (thick areas which solidified relatively slowly) or not (thin areas which were relatively rapidly solidified). Figure 2a–c shows the microstructures of thick foils containing the massive particles on annealing them for 1 h at 573, 673 and 773 K. It may be noted that at low temperatures the Al_9Co_2 phase along the cell boundaries (surrounding the massive particle) gets “pinched off” and appears as discrete particles. The massive particles also show changes in shape and these particles aggregate and assume faceted or nearly spherical shapes at sufficiently high temperatures (figure 2c). The changes in microstructure in thin regions (without massive particles) are shown in figure 3a–c. At a temperature of 623 K, precipitation of Al_9Co_2 in a Widmanstätten pattern takes place and these platelets grow in length and thickness at higher temperatures (figure 3b). From electron diffraction patterns it could be deduced that these platelets bear a close crystallographic relationship with the α -Al matrix. At sufficiently high temperatures, when these platelets grow to a large size, significant strain is introduced between the matrix and the precipitates. Interfacial dislocations can be clearly seen at this stage (figure 3c). Eventually the equilibrium constitution is achieved in all the foils (Menon and Suryanarayana 1986; Van Tendeloo *et al* 1987). Similar results have also been reported by Sater and Sanders (1986). High-resolution electron micrographs and optical diffraction patterns recorded from the Widmanstätten platelets aided in unambiguously identifying them as Al_9Co_2 (Van Tendeloo *et al* 1987).

3.2 Quasicrystalline phases

Traditionally, solid materials have been classified as crystalline or amorphous depending on whether the constituent atoms are arranged regularly in a periodic manner in three dimensions or at random. The remarkable discovery in 1984 by Shechtman *et al* (1984) that rapidly solidified Al–14% Mn, Cr, or Fe alloys exhibit single-crystal electron diffraction patterns with an aperiodic arrangement of spots has evoked considerable interest. These phases, now referred to as quasicrystalline, do not show translational symmetry but possess orientational order. Although the majority of these phases show the five-fold symmetry, eight-fold (Wang *et al* 1987), ten-fold (Bendersky 1985; Chattopadhyay *et al* 1985), twelve-fold (Ishimasa *et al* 1985), and fifteen-fold (Ohashi *et al* 1986) symmetries have also been reported in some alloy systems. A characteristic feature of diffraction patterns from these phases is that the neighbouring pairs of spots along any direction perpendicular to the 5- and 10-fold rotation axes are aperiodic and separated by a distance corresponding to the golden ratio (i.e. $(1 + \sqrt{5})/2 = 1.618\dots$). Two types of quasicrystalline phases have been investigated in detail. The first one is referred to as the icosahedral phase (with five-fold symmetry) and shows aperiodic arrangement of diffraction spots along all the three directions. The second category (with ten-fold symmetry) is one where aperiodicity is observed along two directions, while in the third there is strict periodicity. This one-dimensionally periodic quasicrystalline phase is designated as the *decagonal* phase. Exhaustive and excellent reviews on various aspects of these

Figure 4. Morphological features of the decagonal quasicrystalline phase. (a) Rosette morphology in the Al-14%Co alloy, (b) cellular-dendritic structure in the Al-20%Co alloy, and (c) rosette morphology in the Al-20%Co-5%Si alloy.

Figure 5. Selected area diffraction patterns from the as-rapidly solidified Al-20%Co-5%Si alloy along the (a) 10-fold, (b) 3-fold and (c) 2-fold axes.

quasicrystalline phases, conference proceedings, and a bibliography are available (Bendersky 1986; Gratias 1987; Mackay 1987; Janot and Dubois 1988; Suryanarayana and Jones 1988; Kuo 1990; Ranganathan and Chattopadhyay 1991; Kelton 1993). The reader can refer to these for details.

A decagonal phase is observed in binary Al–Co alloys containing 14 to 25%Co and in a ternary Al–20%Co–5%Si alloy. Figure 4 shows typical microstructures observed in different alloys. The microstructure in the Al–14%Co alloy can be described as consisting of rosettes in an α -Al matrix (figure 4a). High-magnification micrographs reveal these rosettes to be made up of overlapping dendrites. Occasionally, petal-like shapes have also been observed (Suryanarayana and Menon 1987). With increasing cobalt content, the microstructure appears cellular-dendritic in nature (figure 4b). Addition of silicon, however, produces again mostly the rosette structure (figure 4c), even though the contrast appears to be less striking. Occasionally, nodular and plate morphologies have also been observed (Menon 1988; Menon and Suryanarayana 1988b).

Electron diffraction patterns from these alloys are presented in figure 5. While the ten-fold (figure 5a), three-fold (figure 5b) and two-fold (figure 5c) patterns confirm the quasicrystalline nature of the phase produced, the observation of perfect periodicity along one of the directions in figure 5c unambiguously confirms that the quasicrystalline phase produced in these alloys is decagonal in nature. Although the general features of the diffraction patterns are similar in all the alloys, subtle differences have been noticed. The nature and extent of streaking and the density of spots appear to be different (Menon and Suryanarayana 1988b). The quasilattice constant has been calculated to be 0.43 nm for this phase and the periodicity most commonly observed is 1.6 nm.

X-ray chemical analysis in the electron microscope suggests that the cobalt content in the decagonal quasicrystalline phase in all the alloys is about 20%, in conformity with the compositions reported for other icosahedral and decagonal quasicrystalline phases (Suryanarayana and Jones 1988).

Although the formation of a quasicrystalline phase was reported earlier in an Al–14%Co alloy (Dunlap and Dini 1986), this was wrongly interpreted as an icosahedral phase on the basis of X-ray diffraction data. By using the powerful electron diffraction technique we have correctly identified this as a decagonal phase and this has been confirmed later by others (Dong *et al* 1987).

Several criteria have been put forward to explain the formation of quasicrystalline phases. However, occurrence of a cascade of peritectic reactions in the composition range of interest (Phillips 1986) and presence of two-dimensional Penrose tilings in the corresponding equilibrium crystal structures (Kumar *et al* 1986) seem to be responsible for the formation of a decagonal phase in this system. It has been shown later (Ma and Kuo 1992) that decagonal quasicrystalline phases can be obtained in Al–Co alloys in the range $\text{Al}_{11}\text{Co}_4$ to $\text{Al}_{10}\text{Co}_4$ by *slow* solidification. This implies that the quasicrystalline phase in this system has a high thermal stability.

Very fine twin-like features, dislocations and dislocation loops have also been observed in the as-solidified structure. It is suggested that these dislocation loops are formed as a result of the condensation of vacancies on the two-dimensional aperiodic planes which are stacked in a periodic manner to form the decagonal phase (Menon and Suryanarayana 1988c). The “Burger’s” vector of these loops is evaluated to be in the periodic direction with a magnitude equal to the periodicity. Such dislocation

Figure 6. Diffraction patterns showing periodicity along one direction in the decagonal phase. The periodicities are (a) 1.6 nm, (b) 1.2 nm, (c) 0.8 nm and (d) 0.4 nm. These patterns correspond to either the B (the intense spots form a hexagon) or the C (intense spots form a square) types according to the designation of Bendersky (1985).

features in rapidly solidified quasicrystalline phases have been confirmed later by others (Hatwalne and Ramaswamy 1990; Zhang and Urban 1990).

Partial substitution of Al with Si (up to 6%) seems to result in the formation of an icosahedral phase instead of a decagonal phase in Al-Mn alloys containing more than 18% Mn (Chen and Chen 1986; Schaefer *et al* 1986). This was ascribed to a reduction in the effective size of the Al atoms (Schaefer 1986). However, Si additions to Al-Co alloys do not seem to have any appreciable effect and only a decagonal phase formed even in the ternary alloy (Menon and Suryanarayana 1989). The

Figure 7. Transformation behaviour of the quasicrystalline phase in an Al-20%Co alloy. (a) Formation of fine holes during decomposition of the decagonal phase to the crystalline phases. (b) Equilibrium microstructure on complete transformation. Note the very fine equiaxed grain structure. (c) Electron diffraction pattern from the above structure. Al_9Co_2 phase in the $[110]$ orientation.

Figure 8. High-resolution electron micrographs from the decagonal phase in the Al-Co-Si alloy: (a) shows aperiodicity of fringes and (b) shows that the lattice fringes have variable periodicities. Dislocation-like defects can also be seen in (b).

diffraction patterns, however, are more complex and the density of spots is higher. Thus, size factor alone may not be responsible for the preferential formation of the icosahedral phase in Al–Mn–Si alloys. Electronegativity, charge transfer and other factors may also play an important role (Menon 1988).

A consequence of the one-dimensional periodicity in the decagonal phase is that it should be possible to observe the phenomenon of polytypism (Verma and Krishna 1966) in these phases. This has been shown to be theoretically possible by Yamamoto and Ishihara (1988). Figure 6 shows that the periodicity in the decagonal phase can vary from 0.4 nm to 1.6 nm. It should be clarified at this stage that in the binary alloy periodicities of only 0.4, 0.8 and 1.6 nm are observed. Transformation of one polytype into another has been observed during *in situ* transformation and stacking faults seem to play an important role in these transformations (Menon *et al* 1989).

The quasicrystalline phase in all the alloys transformed to the equilibrium crystalline phases on annealing at sufficiently high temperatures and for long enough times. While the quasicrystalline phase in the Al–14%Co alloy transformed completely to the equilibrium phases even at 800 K, that in the Al–25%Co alloy did not show signs of transformation even on heating up to 923 K. Thus, the thermal stability seems to depend on the cobalt content in the alloy.

An interesting observation made during annealing of the quasicrystalline phase was the formation of very fine holes. Very small holes of about 30 nm size were found to be arranged in linear arrays (figure 7a). On continued heating, these holes aggregate resulting in the formation of much larger holes. The volume fraction of these voids was calculated to be about 7%. The density of quasicrystalline phases is known to be 2–6% less than that of its crystalline counterparts (Chen *et al* 1985; Samuel *et al* 1986). Thus, the additional volume in the quasicrystalline phase (due to the lower density) is accommodated during the transformation by the formation of holes (Suryanarayana *et al* 1988).

The quasicrystalline phase eventually transforms to the equilibrium constitution on annealing at sufficiently high temperatures. The equilibrium microstructure in all the alloys can be described as a mixture of two phases. The grain size is very fine and measures approximately 0.5 μm (figure 7b), and a typical diffraction pattern from the Al_9Co_2 phase in an Al–20%Co alloy is shown in figure 7c.

High-resolution electron microscopy is a powerful tool for studying quasicrystalline phases (see, for example, Hiraga *et al* 1987). These investigations can help in deciding the applicability of Penrose tilings for the structure of these phases and also in identifying and characterizing the defects. Figure 8a shows a high-resolution electron micrograph recorded with the aperiodic spots and clearly reveals aperiodicity of the lattice fringes in the ternary Al–Co–Si alloy. Figure 8b shows another micrograph recorded with the periodic spots and variable periodicity of the fringes and dislocation-like defects can be clearly seen in the micrograph and on the whole it can be described as an imperfect structure.

3.3 Amorphous phase

At extremely high rates of solidification achieved in the thinnest portions of the foils, an amorphous phase was detected in the Al–14%Co alloy and its crystallization behaviour was studied (Menon and Suryanarayana 1988d). Figure 9a shows an

Figure 9. (a) Electron micrograph and (b) the corresponding diffraction pattern from very thin portions of a rapidly solidified Al-14%Co alloy foil. Lack of contrast in the micrograph and diffuse haloes in the diffraction pattern confirm the presence of an amorphous phase.

electron micrograph from the amorphous region and the corresponding electron diffraction pattern is shown in figure 9b. The presence of diffuse haloes in the diffraction pattern and absence of diffraction contrast in the micrograph clearly establish the formation of an amorphous phase in this alloy.

There have been many instances of formation of an amorphous phase in metal-metal systems (Suryanarayana 1980b). The reasons for their formation have been many and the most accepted criterion is the existence of a deep eutectic in the alloy system associated with a reasonably high value of T_{gr} , the reduced glass transition temperature (Chen and Jackson 1978). Other factors identified so far include (i) presence of about 20% metalloid elements, (ii) existence of a number of intermetallic compounds in the composition range of interest (Zielinski *et al* 1978), and (iii) atomic volume mismatch (Egami and Waseda 1984). It has also been recently noted that any alloy which forms a quasicrystalline phase on rapid solidification **can** form an amorphous phase at still higher cooling rates (see Suryanarayana and Jones 1988). Considering these factors, it is not surprising that an amorphous phase **is** produced

Figure 10. Sequence of crystallization of the amorphous phase during *in-situ* heating. (a) Micrograph at 473 K showing the beginning of crystallization. (b) Beginning of formation of an equiaxed structure. (c) Equilibrium Al_9Co_2 phase with a fine grain size of about $0.5\ \mu\text{m}$. (d) Electron diffraction pattern from the Al_9Co_2 phase. Foil normal is $[214]$.

in this alloy system. Calculations show that the critical cooling rate required for the formation of an amorphous phase in the Al–Co system is $> 10^8\ \text{K/s}$.

Crystallization behaviour of the amorphous phase was followed through *in situ* heating of the thin amorphous sample in the electron microscope. Figure 10a presents an electron micrograph recorded at about 473 K, when crystallization started. Diffraction patterns from this phase suggest that the phase precipitating from the amorphous matrix is Al_9Co_2 . With continued heating, a fine equiaxed structure of the Al_9Co_2 phase was found to form (figure 10b), and after complete crystallization an equiaxed microstructure is observed (figure 10c). This structure seems to consist of essentially the Al_9Co_2 phase, and a typical diffraction pattern from this is shown in figure 10d. The composition of this phase as determined by energy dispersive X-ray analysis has been found to be the same as that of the amorphous phase and hence it can be concluded that this transformation is of the polymorphic type (Köster and Herold 1981; Ranganathan and Suryanarayana 1985).

4. Conclusions

From the results described above, it becomes clear that Al–Co is an interesting alloy system and rapid solidification of these alloys from the liquid state results in a rich

harvest of metastable phases. Electron microscopy has been shown to be an important investigative technique in characterizing these metastable phases and their transformation to the equilibrium phases. Based on the above results, the following conclusions can be drawn:

1. The solid solubility of Co in Al can be increased to at least 1.7% by melt spinning.
2. The as-solidified structure is not completely homogeneous. Clustering effects and formation of D1_a-type ordered regions are observed in localized regions.
3. Two metastable crystalline phases, (a) b.c.c. with $a = 0.286$ nm and (b) f.c.c. with $a = 0.52$ nm, have been detected in the as-quenched alloys. The b.c.c. phase is the same as β -AlCo, but occurring in a metastable condition at much lower cobalt contents.
4. A decagonal quasicrystalline phase has been found to form in the Al–14 to 25%Co alloys. Partial substitution of Al by Si does not produce an icosahedral phase, as reported in the Al–Mn–Si alloys.
5. Several defects—dislocations, dislocation loops and twin-like features—have been observed in the as-rapidly solidified decagonal quasicrystalline phase.
6. The periodicity of the decagonal phase is found to vary from 0.4 to 1.6 nm, suggesting that these phases can exhibit the phenomenon of polytypism. Transformation from one polytype to another has also been observed.
7. Formation of fine holes has been observed during the transformation of the quasicrystalline phase to the equilibrium crystalline phases. The density difference between the quasicrystalline and crystalline states has been found to be responsible for this.
8. An amorphous phase was produced at very high cooling rates in the Al–14%Co alloy. It crystallizes into the Al₉Co₂ phase by a polymorphic mode.

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