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Directionality in the Mechanical Properties of Spray Cast and Extruded 7XXX Series Aluminium Alloys*

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Abstract

Three 7xxx series aluminium SS70, N707 and 7075 alloys have been produced by the spray deposition process. The alloys were extruded and subsequently heat treated in the T6 and T7 temper conditions. Texture analysis of as-received and solution treated alloys revealed <111> and <100> fibre textures leading to higher mechanical properties in the longitudinal direction. Anisotropic behaviour was observed in these alloys. In addition, the influence of recrystallizing, heat treatment, stretching, and processing techniques (IM, PM and spray casting) as well as techniques of forming (extrusion, rolling and forging) on the anisotropic behaviour of the 7xxx series aluminium alloys was examined.

Key words: Spray casting, aluminium alloys, Texture, Mechanical properties, X-ray diffraction

Introduction

Recently, the spray deposition technique has been developed to produce high density, near net shaped preforms of materials directly from the liquid state as an alternative production method to PM. Spray casting was developed from work carried out by Singer at the University of Swansea, U.K., during the early 1970s (Singer, 1970, 1972). The process was explained schematically in detail (Salamcı, 2001). Spray deposition processing generally consists of two steps: the energetic disintegration of a molten metal by inert gas jets into micron-sized droplets (atomization) and the subsequent deposition of a mixture of solid, liquid, and partially solidified droplets on a surface (deposition) (Lengsfeld, 1995). The spray deposition technique differs from established PM technology in that both the atomization and consolidation processes are combined in a single operation. The reduction in the number of manufacturing steps can lead to significant financial savings. Furthermore, this process is carried out under an inert (typically nitrogen) atmosphere, and therefore the embrittling oxide content can be reduced and thus the ductility and fracture toughness can be improved. Compared to conventional casting spray casting involves a much more rapid solidification which gives the added benefits of extending the maximum solute content of alloying elements, as well as allowing reduced macrosegregation and refinement of the alloy grain size (Lavernia and Grant, 1988).

Anisotropic mechanical properties are important for designers, who can often use a material with enhanced strength in one direction. Little attention has been focused on the the anisotropic behaviour of spray cast 7xxx series aluminium alloys. The objective of the present research was to investigate the texture mechanism of spray cast 7xxx series aluminium alloys and the anisotropic behaviour of the alloys.

Experimental Procedure

The alloys, namely SS70, N707 and 7075, investigated in the present study were produced by Alcan

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Cospray Ltd. at Banbury, U.K., using the spray deposition process. SS70 was spray cast as a cylindrical preform with a diameter of 240 mm and height of 1100 mm and extruded down to a 25 mm diameter rod. The N707 was also spray cast as a preform, which was 235 mm in diameter and 790 mm in height, extruded down to a 63 x 25 mm rectangular section. The 7075 alloy was similarly processed, i.e. spray cast to a $\sim$ 240 mm diameter cylindrical preform and extruded to a 65 x 30 mm rectangular section.

The chemical compositions of the alloys are given in Table 1. Compared to 7075, the zinc contents of SS70 and N707 were significantly increased from 5.4% to 11.5 and 10.9% , respectively, in order to increase strength. In order to control recrystallization and grain growth 0.2% Zr was added to SS70 and N707 instead of Cr, which was used in 7075. SS70 had a slight increase in Zn and Mg content compared to N707. The SS70 and N707 had lower iron and silicon contents (around 0.05-0.03% Fe and 0.02-0.01% Si) compared to the conventional 7075 alloy.

Texture analysis was performed on a Philips APD1700 diffractometer using Cu K_α radiation (λ = 1.5406 Å), set to detect $\{111\}_\alpha$ planes (at a peak angle of 38.47 °). Slices were cut from each extruded section using a Struers Discotom-2 cutting machine to a thickness of 3 mm and an approximate surface area of 500 mm^2. These were ground randomly in different directions on fine silicon carbide paper before x-ray examination to remove any surface texture produced by cutting. The randomly ground samples were mounted on a stub using Plasticine and levelled with a press. Crystallographic texture was determined from the resulting pole figures, which show the distribution of orientations of the $\{111\}_\alpha$ poles about the normal to the sample section.

Tensile test specimens were prepared according to British Standard BSEN 10002-1: 1990. The tensile test specimens used in this work had a gauge length of 25 mm and a diameter of 5 mm and are described in British Standard BSEN 10002-1: 1990. Specimens were machined from the extrusions in the longitudinal (L) direction, which was parallel to the extrusion direction, and in the transverse (T) direction, perpendicular to both the extrusion direction and the shortest side of the billet. Notched tensile test specimens were prepared according to ASTM E 602-91. Specimens were machined from the extrusions in the longitudinal and transverse directions. The tensile and notched tensile tests were performed at room temperature with a crosshead speed of 1 mm min^{-1} using an Instron 1185 testing machine. The fracture toughness K_{IC} values were obtained using the results gained from the notched tensile test specimens. The notch yield ratio (NYR), which is the ratio of the notched tensile strength (NTS) to the tensile yield strength (TYS), was calculated. The correlation between the notch yield ratio and the plane strain fracture toughness K_{IC} for 7xxx aluminium alloys is demonstrated in Figure 1 (Kaufman, 1979). The fracture toughness K_{IC} values were obtained using this figure for each notch yield ratio (NYR).

After machining, all materials were solution heat treated at 470 °C for 0.5 h and then aged to the T6 condition (at 120 °C for 24 h) and T7 condition (the first step of double ageing was carried out at 105 °C and the second step at 175 °C) before testing. At least four samples were tested.

Results and Discussion

X-ray texture analysis was carried out on as-received and solution heat treated samples for all three alloys to determine the type of texture due to extrusion. In this technique, the Bragg angle is fixed for a particular reflection and the specimen rotated about three orthogonal axes to determine the distribution of the {111} poles in the sample. The resulting (111) pole figures from the SS70, N707 and 7075 alloys for the (L) and (L-T) sections are shown in Figures 2, 3 and 4. These pole figures revealed fibre texture, which can be best described by specifying the fibre direction that lies parallel to the extrusion direction in the alloys. As can be seen from Figure 2(a), the (111)

Table 1. Chemical composition of SS70, N707 and 7075 alloys (weight percent).

Alloy	Zn	Mg	Cu	Zr	Cr	Fe	Si	Mn	Al
SS70	11.50	2.64	1.16	0.26	<0.01	0.05	0.02	-	bal.
N707	10.90	2.16	1.01	0.22	<0.01	0.03	0.01	-	bal.
7075	5.6	2.5	1.6	-	0.2	0.4	0.5	0.3	bal.

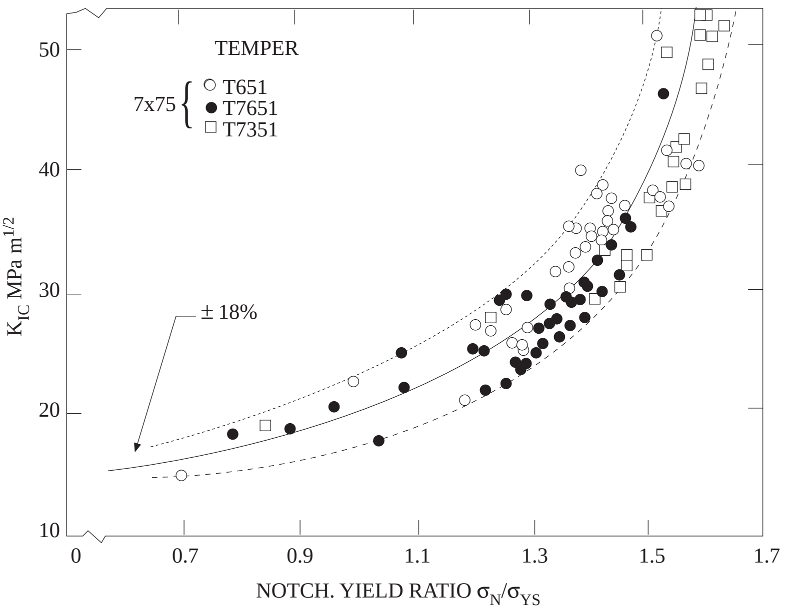

Figure 1. Correlation of plane-strain fracture toughness with notch-yield ratio for 7075 and 7475 plate [after Kaufman (1979)].

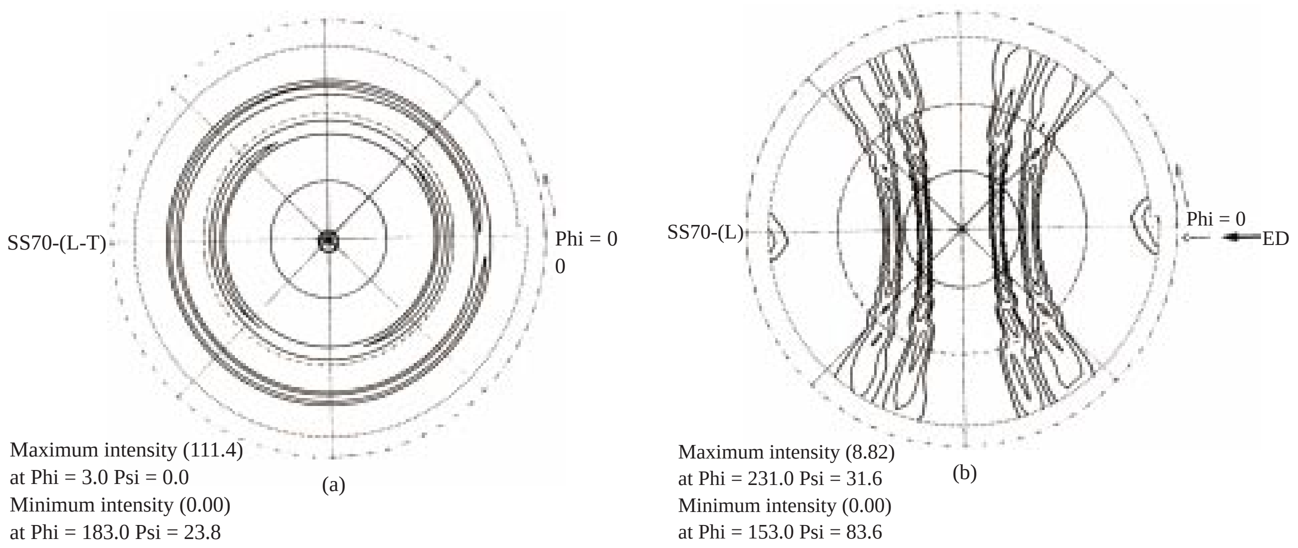

Figure 2. {111} pole figures of as-received SS70 from (a) (L-T) and (b) (L) sections.

pole figure for the (L-T) section of the SS70 alloy shows a central pole and two ring poles at 55 ° and 70 ° from the central pole. This indicates that both <111> and <100> lie along the extrusion direction and thus a dual <111>, <100> fibre texture is present in this sample. This dual texture can also be observed in the pole figure from the (L) section (Figure 2(b)). Figures 3(a)-(b) and 4(a)-(b) show (111) pole figures for the (L) and (L-T) sections of the N707 and 7075 alloys respectively. The (111) pole figure shows a central pole and two arc poles at 55 ° and 70 ° from the central pole instead of the ring poles observed in SS70 because N707 and 7075 alloys were extruded as bars. The resulting textures of SS70, N707 and 7075 may be described as <111>, <100> fibre textures.

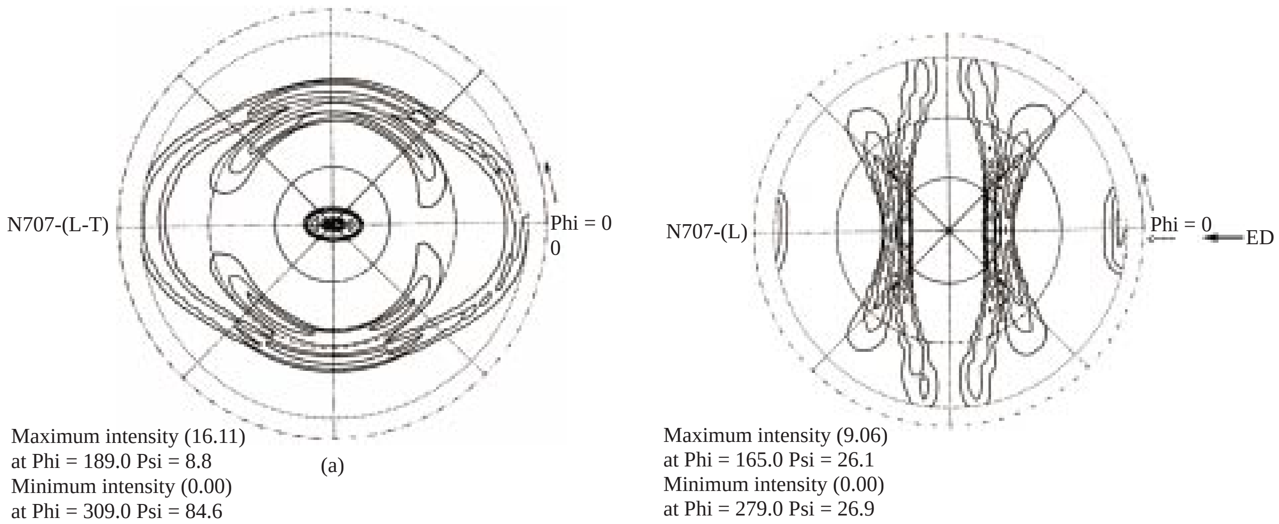

Figure 3. {111} pole figures of as-received N707 from (a) (L-T) and (b) (L) sections.

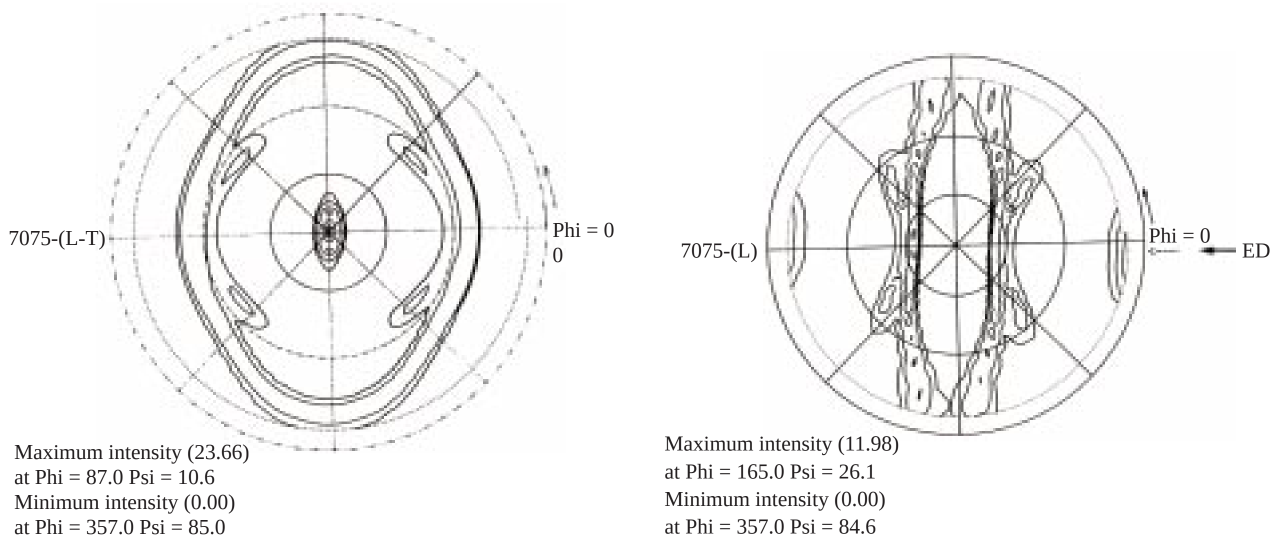

Figure 4. {111} pole figures of as-received 7075 from (a) (L-T) and (b) (L) sections.

(111) pole figures for the (L) and (L-T) sections of the SS70, N707 and 7075 alloys after solution heat treatment were obtained and there was no difference in texture after solution heat treatment

The room temperature mechanical properties of the three alloys, SS70, N707 and 7075, aged to the T6 condition are given in Tables 2 and 3. The results were obtained in the longitudinal (L) and long transverse (T) directions for N707 and 7075; it was not possible to produce a test specimen of SS70 in the T direction because the alloy was only available as a 25 mm diameter rod.

Table 2 shows the results of room temperature tensile testing of unnotched specimens. As can be seen from Table 2 and Figures 5 and 6, anisotropic behaviour was observed. Strength anisotropy was measured by comparing strengths in the longitudinal and transverse directions. N707 and 7075 alloys developed yield strength in the longitudinal direction which was 12% higher than that in the transverse direction. The reason for the increased strength values in the longitudinal direction is the fibre texture developed in the extrusion direction during the extrusion process.

Table 3 shows the results of room temperature notch tensile strength tests of SS70, N707 and 7075 in the T6 condition. As can be seen from Table 3 and Figures 5 and 6, the fracture toughness values in the transverse direction were lower than those in the longitudinal direction. The fracture toughness of N707 and 7075 in the transverse direction was lower by 4.3 MPa $m^{1/2}$ and 2.3 MPa $m^{1/2}$ respectively than those in the longitudinal direction.

Staley (1992) examined metallurgical aspects affecting the strength of heat-treatable alloy products used in the aerospace industry. He reported that, in general, yield strength anisotropy in commercial aluminium alloy products is much lower in flat rolled products and hand forgings than it is in extruded products. This behaviour is illustrated in extruded, rolled plate, and forged 7075 in the T6 condition (Table 4).

Table 2. Average room temperature tensile test results of SS70, N707 an 7075 in the T6 condition.

Alloy	Temper	Orientation	σ_{YS} (MPa)	σ_{UTS} (MPa)	Elong. (%)
SS70	T6	L	755	803	5
N707	T6	L	711	740	5
		T	635	673	5
7075	T6	L	590	656	11
		T	524	588	8

Table 3. Average room temperature notch tensile strength results of SS70, N707 and 7075 in the T6 condition.

Alloy	Temper	Orientation	σ_{YS} (MPa)	σ_N (MPa)	$\sigma_{N/}\sigma_{YS}$	K_{IC} MPa $m^{1/2}$
SS70	T6	L	755	666	0.88	19.6 ± 3.5
N707	T6	L	711	674	0.94	21.2 ± 3.8
		T	635	314	0.5	16.9 ± 3.0
7075	T6	L	590	687	1.16	25.5 ± 4.6
		T	524	560	1.07	23.2 ± 4.2

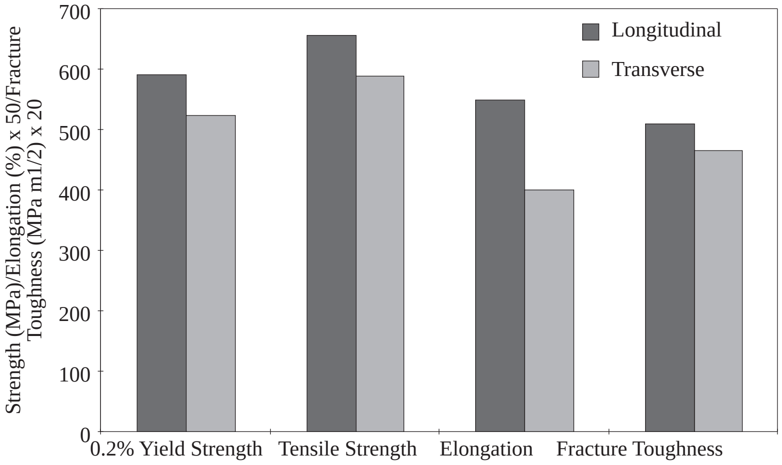

Figure 5. Comparison of mechanical properties of peak aged (T6 temper) 7075 alloys for the transverse direction with those for the longitudinal direction.

He also reported that anisotropy can be eliminated by overageing or recrystallizing the products. This behaviour is shown in unrecrystallized and recrystallized 2024, which is the Cu-Mn-Al alloy and the T6 (peak ageing) and T7 (overageing) treated 7xxx series aluminium alloys (Tables 5 and 6).

White *et al.* (1994) investigated spray deposited and stretched 2% UL30, which is the Al-Li alloy. They observed that stretching significantly increases strength anisotropy. This behaviour is shown in unstretched and stretched 2% UL30 (Table 7).

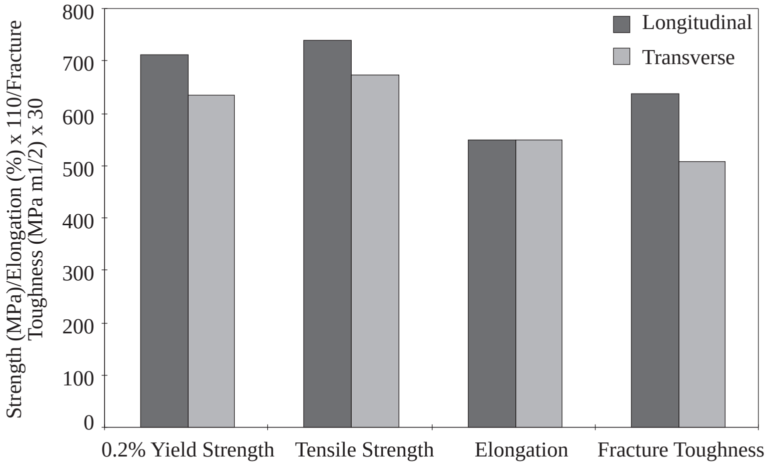

Figure 6. Comparison of mechanical properties of peak aged (T6 temper) N707 alloys for the transverse direction with those for the longitudinal direction.

Table 4. Yield strength values in L and T orientations from extruded, rolled and forged 7075 in the T6 condition.

Orientation	Extrusions (37 to 75 mm)	Plate (51 to 63 mm)	Forgings (51 to 75 mm)
L, σ_{YS}	530	455	425
T, σ_{YS}	410	455	410

Table 5. Yield strength values in L and T orientations from unrecrystallized and recrystallized 2024 aluminium alloy.

	Unrecrystallized		Recrystallized	
Test direction	L	T	L	T
σ_{YS}, MPa	226	211	160	160

Table 6. Yield strength values in L and T orientations from spray deposited 7000 series aluminium alloys in the T6 and T7 conditions.

Alloy	Orientation	T6 Temper	T7 Temper	Reference
Al-Zn-Mg-Cu (7000 series)	L, σ_{YS}	705	503	Machler *et al.*
	T, σ_{YS}	620	482	
N707	L, σ_{YS}	711	590	This work
	T, σ_{YS}	635	524	
7075	L, σ_{YS}	544	513	This work
	T, σ_{YS}	513	481	

Table 7. Yield strength values in L and T orientations from unstretched UL30 and stretched 2% UL30: all specimens were in peak aged condition.

Alloy	Orientation	σ_{YS}(MN m^{-2})
UL30, Unstretched	L	503
	T	459
UL30, stretched 2%	L	580
	T	456

Table 8. Yield strength values in L and T orientations from IM, PM and spray processed 7xxx series aluminium alloys in the T6 condition.

Alloy	Orientation	IM	PM	Spray	Reference
7475-T6	L, σ_{YS}	577	554	562	Faure and Ackermann
	T, σ_{YS}	510	515	512	
High solute 7xxx-T6	L, σ_{YS}	-	773	790	Faure and Dubost
	T, σ_{YS}	-	685	675	

Table 8 shows comparisons between the anisotropic behaviour of spray deposited 7xxx series aluminium alloys and ingot (IM) and powder metallurgy (PM) processed 7xxx series aluminium alloys. IM processed 7475 alloy exhibits the highest degree of anisotropic behaviour. It developed yield strength in the longitudinal direction 13% higher than that in the transverse direction. Spray processed 7475 alloy is more anisotropic than PM processed 7475 alloy. Spray processed high solute 7xxx series aluminium alloy is also more anisotropic than PM processed high solute 7xxx series aluminium alloy.

Conclusions

A difference in mechanical properties was found between the transverse and longitudinal directions; proof stress, tensile strength, fracture toughness and elongation values were all lower in the transverse direction. The reason for this increase in the longitudinal direction is the fibre texture developed in the extrusion direction during the extrusion process.

IM processed 7xxx series aluminium alloys exhibited the highest degree of anisotropic behaviour. Compared with the PM processed 7xxx series aluminium alloys, spray processed 7xxx series aluminium alloys exhibited more anisotropic behaviour.

Similar textures were observed in the three aluminium alloys. The resulting textures of SS70, N707 and 7075 were identified as <111>, <100> fibre textures. In addition after solution heat treatment, a difference in texture was not observed.

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