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Comparison of Unextruded Air Slip Direct Chill Cast 6061 Ingot with Bar Stock Extruded from Conventional Direct Chill Cast 6061 Ingot

S.C. Bergsma and M.E. Kassner

Air Slip direct chill cast 6061 small diameter ingots (Direct Forge) were compared with 6061 extruded bar stock. The T6 mechanical properties were compared for both the Direct Forge ingot and the extruded bar stock, as well as cold impact extruded cylinders produced from Direct Forge small diameter ingot and extruded stock. It was found that the tensile and fatigue properties of Direct Forge ingot and cylinders from this ingot were significantly superior to those of extruded stock and cylinder produced from this stock. The improved properties are a result of higher solidification rates leading to smaller alloy-constituent dispersed particles and, thus, the production of smaller and more stable grain sizes. Direct Forge has the additional advantages of (a) not requiring hot or cold work prior to forming impacted extruded or forged parts, (b) being utilized in the T6 temper without any prior deformation, (c) having isotropic and consistent properties, (d) not requiring machining to remove surface segregation or defects, and (e) having more consistent and refined grain sizes.

Keywords aluminum alloy 6061-T6, extrusion, mechanical properties, processing aluminum alloys

1. Introduction

This report compares the properties of 6061 small diameter ingot produced by Air Slip direct chill casting (ASDC) (Direct Forge by Northwest Aluminum Company [NWA]) using Wagstaff tooling and extrusions from conventional direct chill (CDC) castings. It also compares the properties of parts formed from these materials. Inverse segregation, porosity, and surface defects are less pronounced in Direct Forge ingots. For this reason, bar stock is normally extruded from CDC ingot to remove the surface segregation, that is, surface skin that can cause a variety of defects and microporosity at the surface and in the interior. This is particularly important for relatively small diameter (less than 114 mm, or 4.5 in.) extruded stock that can be forged. If these conventional cast ingots are not extruded prior to forging, the mechanical properties can suffer in terms of ductility and surface quality. If the properties of unextruded Direct Forge ingot and parts forged from this ingot are comparable to conventional extruded ingot and parts forged from this stock, the cost advantage of Direct Forge ingot could be significant.

This study compares the 6061-T6 tensile and fatigue properties of Direct Forge ingot with extruded CDC ingot (cast with a mold bore in excess of 51 mm, or 2 in.). Furthermore, the mechanical properties of cold-impact extruded parts made from Direct Forge ingot are compared to parts using extruded CDC ingot.

2. Experimental Procedures

Two types of ingots were used: direct chill cast alloy using Wagstaff Air Slip (Wagstaff Engineering Inc., Spokane, WA) tooling for direct chill casting of 61 mm (2.4 in.) diameter ingot produced at the Northwest Aluminum Company and 6061 extruded stock produced from CDC ingots (5 to 10 times slower solidification rate). This extrusion stock was, typically, initially 230 to 380 mm (9 to 15 in.) in diameter and was extruded to diameters of 61 mm (2.4 in.), which was comparable to the Direct Forge ingot. Both stocks were cold impact extruded by Bruin Company, Midland, Ontario, Canada.

All mechanical testing was performed at Oregon State University using an Instron 4505 and Instron servohydraulic 8521 (Instron Corporation, Canton, MA). Typical strain rates were 6.67×10^{-4} s^{-1}. The T6(solution anneal and age, temperatures, and times) treatment for NWA ingots was 549 °C for 1.5 h followed by a water quench and an 8 h age at 177 °C. The extruded CDC ingot was solution treated at 529 °C for 1 h (or 549 °C for 1.5 h) and water quenched followed by an 8 h age at 177 °C. Some of the extruded stock used the NWA recommended T-6 solution treatment (Tables 1, 2). The 549 °C is a NWA recommendation for solution treatment for Direct

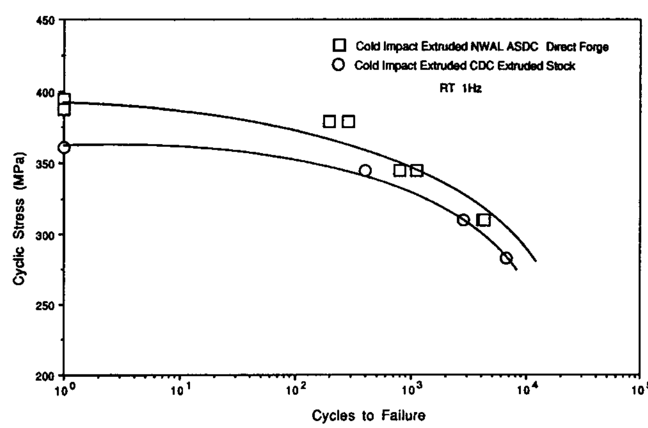

Fig. 1 The engineering stress versus cycles to failure (S-N behavior) of extruded cylinders using 6061-T6 from ASDC Northwest Aluminum Direct Forge ingot and conventional direct chill extruded stock

S.C. Bergsma, Northwest Aluminum Company, The Dalles, OR 97058, USA; **M.E. Kassner,** Oregon State University, Corvallis, OR 97331, USA.

Forge 6061 ingot. The NWA ingot preheat treatment is proprietary, and the preheat treatment of the other extruded stock is unknown. Prior to cold impact extrusion into the final product, the ingots were always in the "O" (fully annealed) condition. The composition of the alloys used in this study is listed in Table 1. The 6061 ingot used by NWA for Direct Forge is similar to the composition of the extruded stock.

The extrusions at the Bruin Company were cylinders approximately 286 mm (11.25 in.) in length and 60 mm (2.375 in.) in diameter with a wall thickness of approximately 5 mm (0.19 in.). Tensile specimens were extracted longitudinally from the cylinder wall. Tensile specimens extracted from the Direct Forge ingots and extruded stock were both longitudinal and transverse to the extrusion/ingot axes.

3. Results

Table 2 lists the mechanical property results from the NWA Direct Forge CDC extrusion stock and the cold impact extruded parts fabricated from these starting ingots and extruded stock. Individual entries (e.g., longitudinal or transverse) are actually an average of four to six tests from two to three different composition ingots listed in Table 1.

These results show that cold impact 6061-T6 extruded parts fabricated from Direct Forge ingot have superior strength (by about 15%) compared to those fabricated from CDC extruded stock. The ductilities appear to be about the same. The properties based on both stocks are also shown. Again, Direct Forge is 15% superior in terms of strength and equal ductility. Figure 1 compares the fatigue properties of the extruded cylinder using Direct Forge and CDC extruded stock. The fatigue properties of Direct Forge are superior.

Figure 2 shows optical micrographs of the impact extruded cylinders parallel to the longitudinal direction after T6 treatment. The micrographs show that the Direct Forge structure recrystallized (average grain size 16 μm) during the solution treatment subsequent to impact extrusion. The grain size remained relatively fine as a consequence of rapid solidification in Air Slip casting, which leads to a finer dispersion of precipi-

Table 1 Composition of alloys used in this study

	Composition, wt%										
Alloy	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	V	Ga
RD0633 61 mm, 2.4 in. diam extruded stock	0.7	0.16	0.3	0.02	1.02	0.05	...	0.05	0.024	0.02	0.01
RD0773-A 76.2 mm, 3 in. diam extruded stock	0.67	0.24	0.23	...	0.93	0.06	...	...	0.013	0.01	...
RD0773-B 70 × 89 mm, 2.75 × 3.5 in. rectangular extruded stock	0.62	0.18	0.22	...	0.88	0.05	...	...	...	0.01	0.01
C1752-2, NWA 61 mm, 2.4 in. diam ingot	0.68	0.27	0.25	...	0.92	0.06	...	0.01	0.02	0.01	0.02
C1977-4, NWA 61 mm, 2.4 in. diam ingot	0.73	0.23	0.36	...	1.12	0.06	...	0.01	0.03	0.03	0.02
C2063-2 NWA 61 mm, 2.4 in. diam ingot	0.75	0.21	0.35	0.03	1.08	0.06	...	0.01	0.03	0.01	0.01
RD0557 NWA 61 mm, 2.4 in. diam ingot	0.65	0.21	0.32	...	0.99	0.06	...	...	0.027	0.01	0.01
RD0558 NWA 61 mm, 2.4 in. diam ingot	0.66	0.2	0.31	0.02	1.01	0.06	...	0.02	0.28	0.01	0.01

NWA refers to Northwest Aluminum Company

Table 2 Mechanical properties of NWA Direct Forge conventional direct chill extrusion stock and cold impact extruded parts

	Yield strength		Ultimate tensile strength		Elongation,	Reduction of area,	Number of
Stock	MPa	ksi	MPa	ksi	%	%	specimens
CDC extruded stock							
Longitudinal(b)	311	45.1	337	48.9	15.8	38.9	4
Longitudinal(a)	290	42.1	311	45.1	16.9	39.8	4
Transverse(a)	319	46.2	356	51.6	9.9	20.1	4
Average CED extruded stock	304	44.1	334	48.4	13	30	8
NWA ASCD Direct Forge							
Longitudinal(b)	338	49.0	386	56.0	18.1	39.6	6
Transverse(b)	345	50.0	379	55.0	17.2	38.4	6
Average NWA ASCD Direct Forge	341	49.5	383	55.5	17.7	39.0	12
Aluminum standards, typical (Ref 1)	276	40.0	310	45.0	12	...	...

(a) T6, 529 °C for 1.5 h, water quenched, refrigerated 0.75 h, 8 h age at 177 °C. (b) 549 °C for 1.5 h, water quenched, refrigerated 0.75 h, 8 h age at 177 °C tates. The cylinder impact extruded from CDC stock also had a recrystallized structure (average grain size 34 μm), but this structure appeared to show more evidence of grain growth.

The average grain size of Direct Forge ingot is about 80 μm. The grain size of the CDC extruded stock is about 2000 μm in the transverse plane and can exceed 10 mm in the longitudinal direction (both after T6). Figure 3 summarizes the properties of NWA ADSC, conventional DC extruded stock and typical properties of 6061-T6 (Ref 1).

Figure 4 compares transverse sections of 6061-T6 NWA Direct Forge (61 mm diam) with CDC extruded stock (76 mm diam). It shows that NWA has a smaller, more homogeneous grain size.

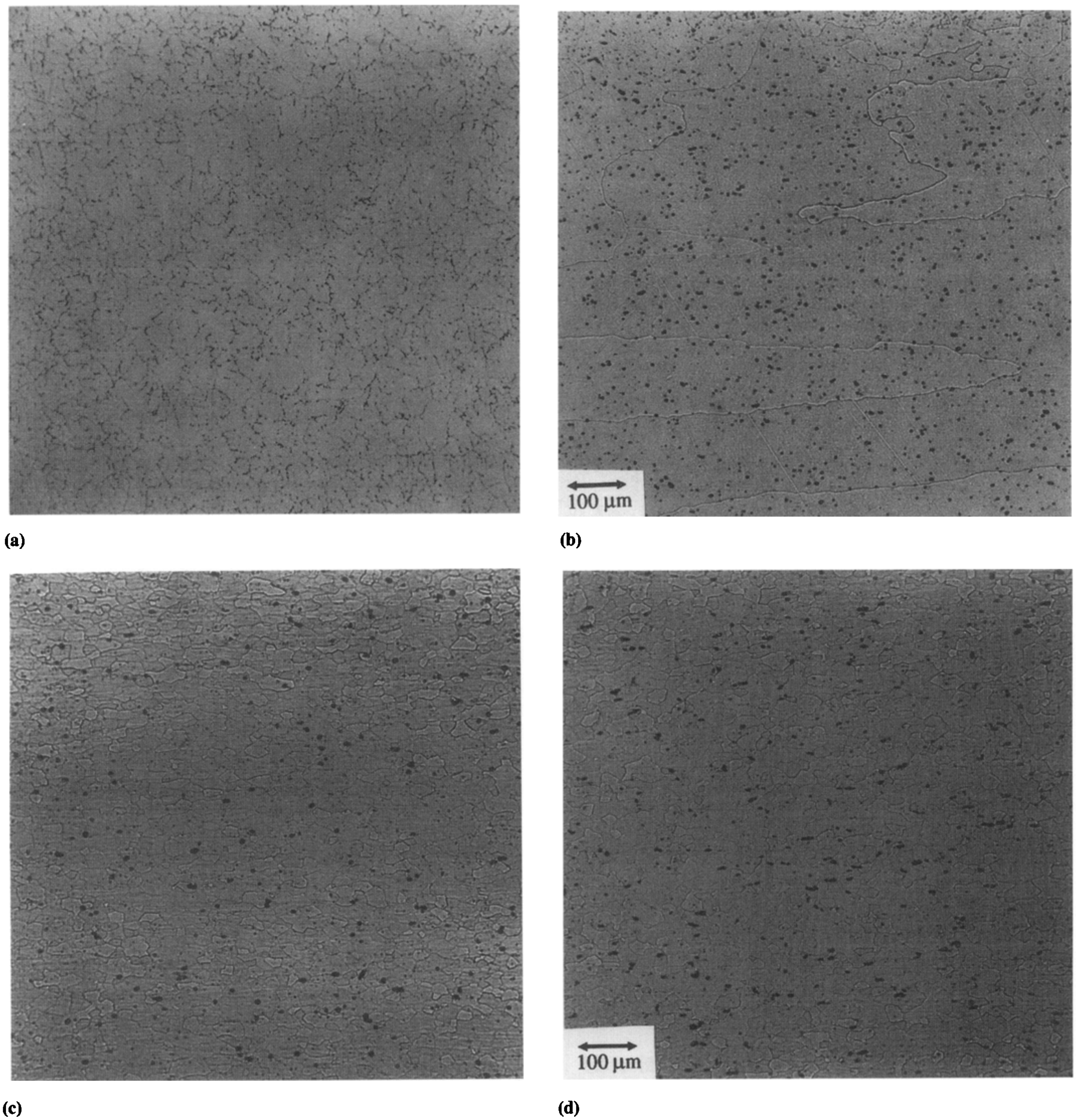

Fig. 2 Optical micrographs of (a) Air Slip direct chill cast 61 mm (2.4 in.) diameter Northwest Aluminum Direct Forge 6061 ingot, (b) extruded 6061 stock 76.2 mm (3 in.) diameter, (c) the extruded cylinder, parallel to the longitudinal direction after T6 treatment for Air Slip direct chill cast Northwest Aluminum Direct Forge ingot, and (d) extruded stock of conventional direct chill cast ingots

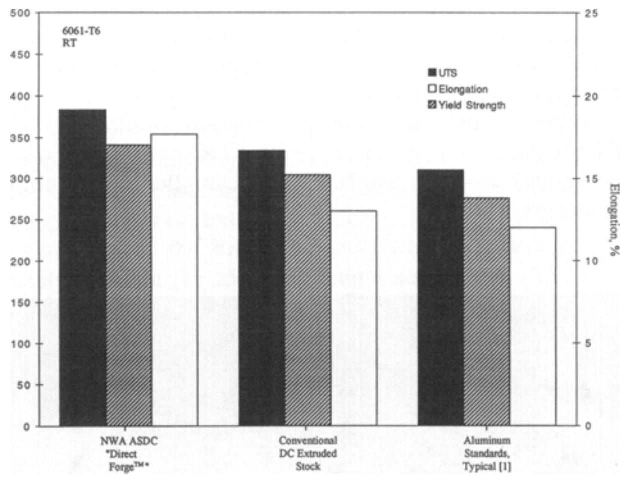

Fig. 3 The bar chart summary of Table 2 showing superior properties of Air Slip direct chill cast Northwest Aluminum Direct Forge ingots, both extruded and unextruded, compared to extruded stock and extrusions from extruded stock

4. Conclusions

- The tensile and fatigue mechanical properties of Direct Forge small-diameter 6061 ingot and impact extrusions from these ingots are superior to conventional extruded stock and extrusion from this stock. This is the result of higher solidification rates during casting (and proprietary preheat treatments at NWA) leading to smaller alloy constituents, dispersoid particles, and more stable fine grain sizes.
- Additionally, Direct Forge ingots do not require hot or cold work prior to forming finished impact extruded or forged parts. Also, they can be utilized in the T6 temper without any prior deformation. Properties are very consistent and isotropic. In most cases, Direct Forge ingots do not require machining to remove surface segregation or defects. Direct Forge allows for better grain size control in the finished part.

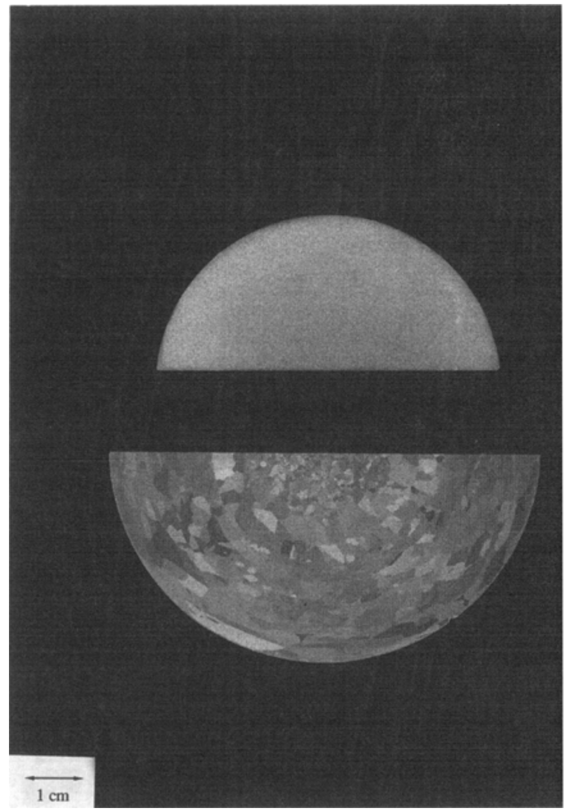

Fig. 4 Comparison of transverse sections of 6061-T6 of Northwest Aluminum Direct Forge (61 mm, or 2.4 in.) and CDC extruded (76.2 mm, or 3 in.) stock

Reference

1. "Aluminum Standards and Data 1997," Aluminum Association, Inc., Oct 1996