The Effect of Ingot Processing Treatments on the Grain Size and Properties of Al Alloy 7075

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An investigation was carried out to determine the effect of various ingot thermal mechanical processing treatments on the grain size and mechanical properties of high purity homogeneous 7075 aluminum alloy sheet and plate. The results indicate that the recrystallization of 7075 alloy into a fine grained structure can be controlled by the distribution of the Cr in the microstructure, as well as by the distribution of the major alloying elements, Zn, Mg and Cu. A new ingot processing technique, FA-ITMT, was developed for producing fine grained 7075 sheet and plate. Data are presented which show that fine grained 7075 sheet and plate have equivalent strength and significantly better ductility than conventionally processed material.

THE major shortcomings of commercial high strength wrought 7000 series aluminum alloys are low ductility, low toughness and poor stress corrosion resistance, especially in the short transverse direction. Frankford Arsenal has been conducting studies aimed at eliminating these deficiencies and improving the strength of these alloys through the use of improved processing techniques. The early work in this area[1-4] showed that elimination of second phase constituents induced substantial improvements in ductility and toughness and some improvement in fatigue resistance at equivalent strength levels when compared to commercial alloys. These improvements were achieved by the use of high purity materials, by controlled solidification techniques to achieve a small dendrite arm spacing and by optimum homogenization treatments.

Other work directed towards improving the properties of 7000 series alloys, carried out at Instituto Sperimentale dei Metalli Leggeri (ISML) under a US/Italy cooperative research program, has been reported by DiRusso *et al.*[5,6] In that work, a new technique termed final thermal mechanical treatment (FTMT) was developed. This technique involves the application of plastic deformation between an initial and a final artificial aging step. With FTMT the strength of the 7000 series alloys can be increased by 20 to 25 pct with only a minimal loss of ductility and toughness.

In addition to the property improvements achieved by better solidification techniques and by advanced thermal mechanical treatments (FTMT), it was considered that improvements could also be achieved by controlling the grain morphology. Although there is much information on the effect of grain morphology in pure metals and solid solution alloys, little data are available regarding high strength aluminum alloys. Therefore, the US/Italy cooperative research program carried out at ISML also included investigations on grain morphology effects. The results of those studies[7-9] showed that in 7075 alloy the properties related to ductility, such as elongation, reduction in area, and toughness were improved by the use of an intermediate thermal mechanical treatment (ITMT) which was designed to produce a wrought product with grains that are finer than those obtained by conventional processing. Preliminary work also indicated that forged 7075 plate processed by ITMT exhibited improved stress corrosion resistance.[10]

ITMT involves a new concept in ingot processing in that the original cast grain boundaries are eliminated by a recrystallization step prior to conventionally working the material into the final wrought products. In the ITMT process reported by DiRusso *et al*,[7-10] *i.e.*, ISML-ITMT, the 7075 ingots are partially homogenized, worked at relatively low temperatures, recrystallized, homogenized and then conventionally hot worked into wrought products. The ITMT products can be utilized in the as-recrystallized (AR) condition or in the as-recrystallized plus hot rolled (AR + HR) condition.

According to DiRusso *et al*,[7-9] the success of the ISML-ITMT process is based upon making the Cr ineffective in retarding recrystallization of the worked ingot into a fine grain structure. The ISML-ITMT process accomplishes this by maintaining most of the Cr in supersaturated solid solution in the aluminum-rich matrix during both the partial homogenization and low temperature deformation stages. Subsequent recrystallization and homogenization of the ISML-ITMT material produces a fine grain structure followed by precipitation of the remaining Cr. DiRusso *et al*[7-9] state that a fine grain structure is not produced during conventional processing because in contrast to the ISML-ITMT process, the Cr precipitates during the initial thermal treatment prior to working. In addition, they state that dynamic recovery occurs during the working operation; this also hinders recrystallization into a fine grain structure.

Realizing the broad potential that ITMT has an improving the performance of Army materiel, especially in such mill products as rolled plate, a broad program was initiated at Frankford Arsenal to study in more detail the various parameters involved in ingot processing. This paper presents the results concerned with the effect of selected experimental ingot processing treatments on the grain structure and mechanical properties of wrought high purity homogeneous 7075 sheet and plate. The selection of the experimental treatments was based on examining not only the effect of Cr, but also the effect of Zn, Mg and Cu in producing fine grained wrought 7075.

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EXPERIMENTAL PROCEDURE

Material

High purity homogeneous 7075 sheet and plate of several thicknesses were produced and evaluated. In order to study the effect of grain size and shape, the materials were produced in the as-recrystallized (AR) and in the as-recrystallized plus hot rolled (AR + HR) conditions. Specifically, AR + HR 0.160 in. thick sheet, AR 0.7 in. thick, AR + HR 0.4 in. thick and both AR and AR + HR 1 in. thick plate were produced. The details of the materials evaluated are described below.

Billets, 1.5 in. thick by 2.5 in. wide by 4.5 in. long, were used to produce the 0.160 in. thick sheet. The billets were prepared from a 500 lb. (6 in. thick by 16 in. wide by 56 in. long) direct chill cast high purity ingot of 7075 (Al-5.5 pct Zn-2.5 pct Mg-1.57 pct Cu-0.20 pct Cr-0.01 pct Si-0.00 pct Fe). The ingot was stress relieved at 650°F for 12 to 14 h.

Double wedge shaped billets 6 in. long and 7 in. wide and having a trapezoidal cross-section of 2.3 in. maximum thickness and 0.7 in. minimum thickness were used to produce the 0.7 and 0.4 in. thick plates. A wedge shaped billet was used in order to produce various degrees of initial deformation and hence, different as-recrystallized grain sizes in each plate. The billets were cut from the ingot described above.

Billets, 5.35 in. thick by 12 in. wide by 24 in. long and 9 in. thick by 12 in. wide by 24 in. long, were used to produce the 1 in. thick AR and AR + HR plates, respectively. The billets were cut from a 5000 lb. direct chill case ingot (12 in. thick by 38 in. wide) of high purity 7075 (Al-5.53 pct Zn-2.43 pct Mg-1.53 pct Cu-0.20 pct Cr-0.04 pct Ti-0.02 pct Si-0.02 pct Fe) which had been stress relieved at 650°F for 8 h.

Ingot Processing Treatments

The various ingot processing treatments used to produce the sheet and plate are shown schematically in Fig. 1. The details of each treatment are listed in Table I. The experimental ingot processing treatments involved those in which the Cr was precipitated out of solution prior to the initial deformation. As can be seen these treatments utilized a high temperature homogenization prior to the initial deformation step which has been shown by extensive electron microscopy studies to precipitate the Cr out of supersaturated solid solution in the Al-rich matrix.[7-9] The experimental treatments are Nos. 1, 2, 5, 8, 9.

In addition to material produced by the experimental ingot processing techniques, both conventionally processed material and ISML-ITMT processed material were examined for comparison purposes. The conventional processing technique is designated by Treatment Nos. 3 and 6. The ISML-ITMT technique is designated by Treatment Nos. 4, 7, 10, 11 and 12. As can be seen from Table I, some of the treatments selected were used to produce material in only the AR condition, or in the AR + HR condition, while others were used to produce material in both the AR and AR + HR conditions.

In this investigation, rolling in only one direction was used as the means of deformation. All of the thermal treatments, except the artificial aging treatments were carried out in a salt bath to ensure a rapid heating rate to the desired temperature and to prevent any possible high temperature oxidation. The artificial aging treatments were done in an air circulating furnace. All of the materials were evaluated in the T6 temper which consisted of a solution heat treatment at 900°F for 1 h (sheet) or 3 h (plate), cold water quench, natural age 5 days and artificial age at 250°F for 24 h. The 1 in. thick plates were also evaluated in the T76 (250°F/4h + 325°F/18 h) and T73 (225°F/6 h + 350°F/8 h) tempers using the solution heat treatment, quench and natural aging treatments that were utilized for the T6 temper. The various tempers were monitored by means of electrical conductivity measurements.

Microstructural Examination

Conventional metallographic procedures were used to prepare samples for optical microscopic examination. Longitudinal sections of each material were prepared and etched with Keller's etch. The grain sizes of the various structures produced in the 0.4 and 0.7 in. thick plate materials were determined using lineal analysis. The measurements were taken on longitudi-

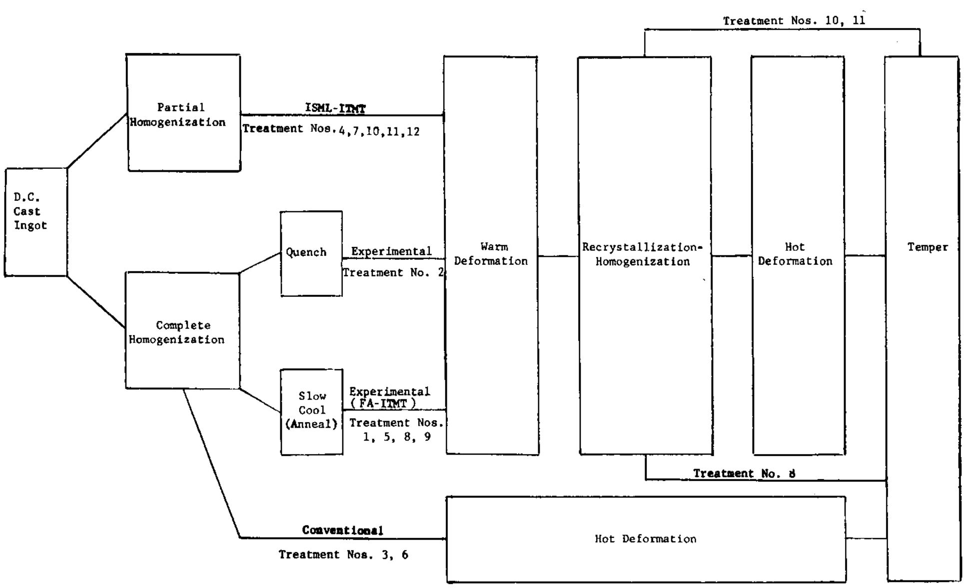


Fig. 1—Schematic diagram of the various ingot processing treatments used. For detailed explanation of each treatment refer to Table I.

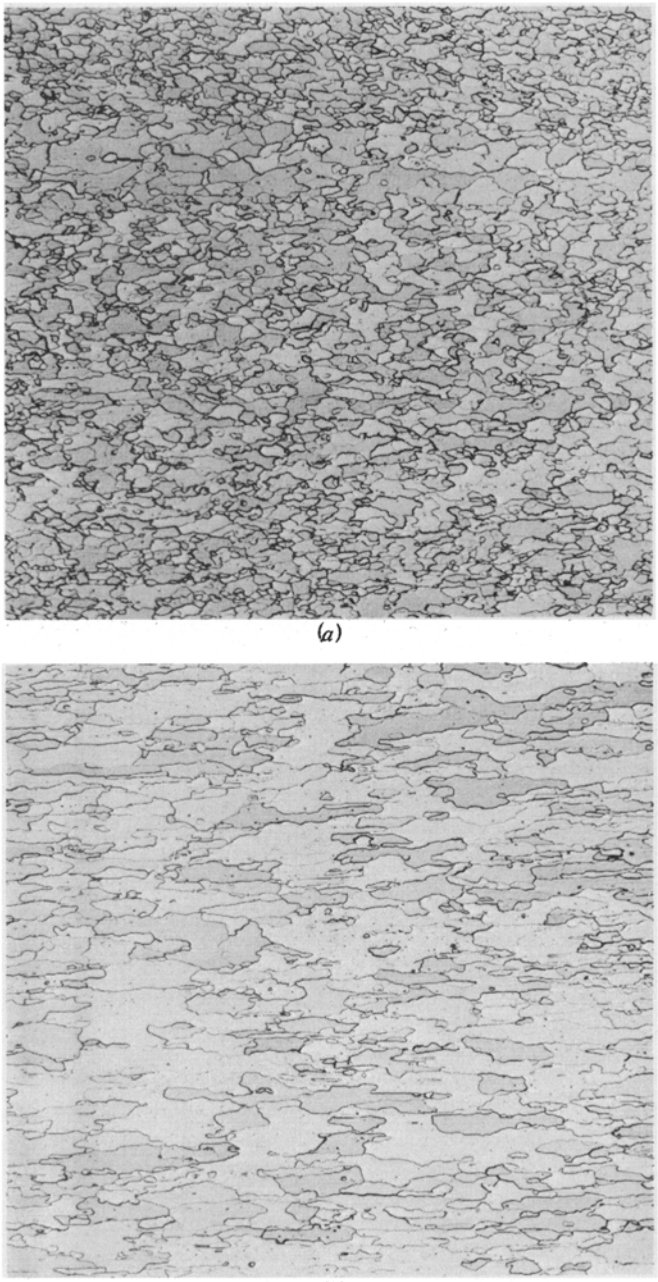


Fig. 2—Microstructures of 7075 given Experimental Treatment 1 (FA-ITMT). Longitudinal Sections. Magnification 100 times. Keller's etch. (*a*) As-recrystallized and (*b*) Recrystallized, hot rolled and T6.

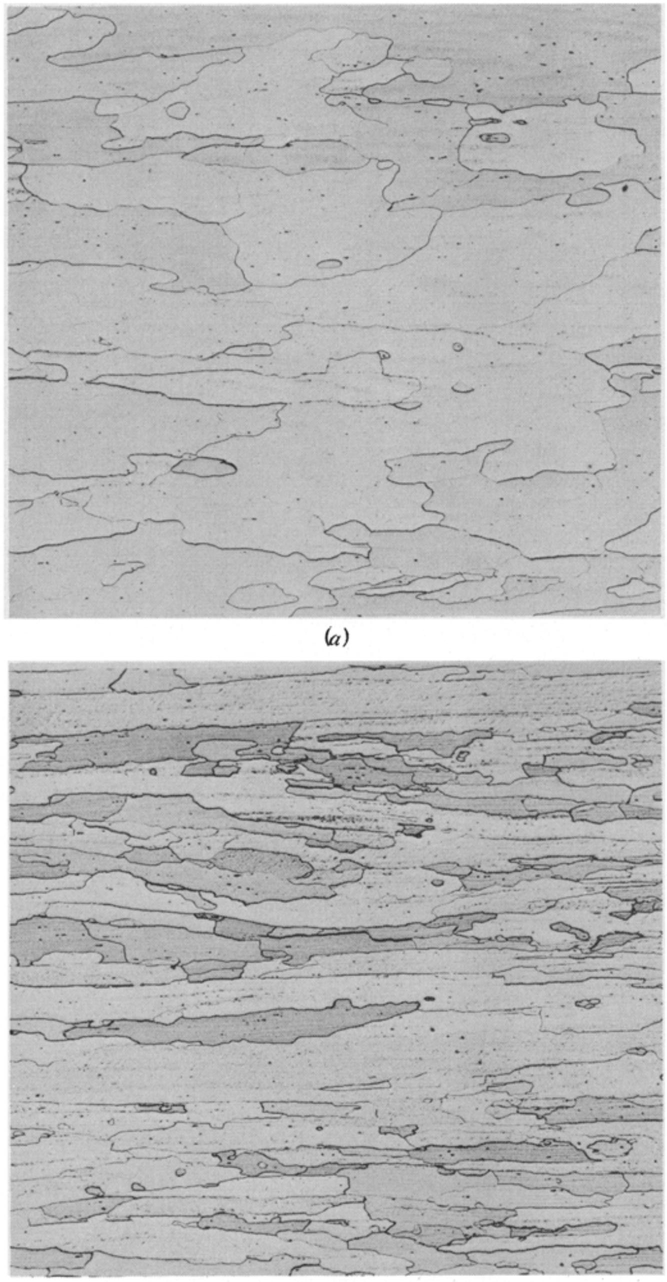


Fig. 3—Microstructures of 7075 given Experimental Treatment 2. Longitudinal Sections. Magnification 100 times. Keller's etch. (*a*) After intermediate thermal treatment and (*b*) After intermediate thermal treatment, hot rolled and T6.

nal sections in directions that were parallel and perpendicular to the rolling direction; thus the grain diameters are specified $D_{\parallel}$ or $D_{\perp}$. Electron microprobe measurements were carried out in order to determine the distribution of the solute elements (Zn and Cu) after the homogenization step prior to the initial deformation step in each of the various ingot processing treatments. The Mg distributions were not obtained due to the high absorption of Mg X-rays by the Zn and Cu in 7075.

Mechanical Testing

Duplicate long transverse 0.113 in. diam, single long transverse 0.252 in. diam, and duplicate longitudinal and long transverse 0.505 in. diam tensile specimens (designed according to ASTM standard E-8) were made from the sheet, 0.4 and 0.7 in. thick plate and 1 in. thick plate, respectively. All of the tensile specimens were machined from the center plane of each material. Testing was carried out using a Tinius Olsen mechanical type universal tensile testing machine operating at a strain rate of 0.05 per min.

RESULTS AND DISCUSSION

Sheet

The microstructures of the sheet produced using the experimental techniques, the conventional processing

Table I. Ingot Processing Treatments Used on 7075 Alloy

Treatment No.	Process	Billet Thickness, in.	Initial Homogenization Treatment, h/°F	Initial Deformation pct/°F	Thickness After Initial Deformation, in.	Recrystallization Homogenization Treatment, h/°F	Final Deformation pct/°F	Final Thickness in.
				Sheet				
1	Experimental (FA-ITMT)	1.5	7/860 + 17/900, *F.C.* to 775, 5/775, *F.C.* to 500, 4/500	70.5/500, *A.C.* to *R.T.*	0.443	7/860 + 17/900, *F.C.* to 800	64/800 *A.C.* to *R.T.*	0.160
2	Experimental	1.5	7/860 + 17/900, *Q*, 1/625	70.5/625, *A.C.* to *R.T.*	0.443	7/860 + 17/900, *F.C.* to 800	64/800, *A.C.* to *R.T.*	0.160
3	Conventional	1.5	7/860 + 17/900, *F.C.* to 800	89.5/800, *A.C.* to *R.T.*	–	–	–	0.160
4	ISML-ITMT	1.5	1/625	70.5/625 *A.C.* to *R.T.*	0.443	7/860 + 17/900, *F.C.* to 800	64/800, *A.C.* to *R.T.*	0.160
				Plate (Wedge Studies)				
5	Experimental (FA-ITMT)	2.3 – 0.7	8/860 + 16/900, *F.C.* to 775, 5/775, *F.C.* to 500, 4/500	0-68/500, *Q*	0.725	8/860 + 16/900, *Q*, 1/800	40/800, *Q*	0.431
6	Conventional	2.3 – 0.7	8/860 + 16/900, *A.C.* to *R.T.*, 2/800	1-70/800, *Q*	0.685	8/860 + 16/900, *Q*, 1/800	40/800, *Q*	0.416
7	ISML-ITMT	2.3 – 0.7	8/750, *A.C.* to *R.T.*, 2/625	5-70/625, *Q*	0.708	8/860 + 16/900, *Q*, 1/800	40/800, *Q*	0.425
				Plate				
8	Experimental (FA-ITMT)	5.35	24/860, *F.C.* to 775, 6/775, *F.C.* to 500, 4/500, *Q*, 3.5/500	81/500, *A.C.* to *R.T.*	1.00	48/860, *Q*	–	–
9	Experimental (FA-ITMT)	9.00	24/860, *F.C.* to 775, 6/775, *F.C.* to 500, 4/500, *Q*, 4/400	81/400, *A.C.* to *R.T.*	1.67	48/860, *Q*	40/800	1.00
10	ISML-ITMT	5.35	16/750, *Q*, 4/625	81/625, *A.C.* to *R.T.*	1.00	48/860, *Q*	–	–
11	ISML-ITMT	5.35	16/750, *Q*, 4/550	81/550, *A.C.* to *R.T.*	1.00	48/860, *Q*	–	–
12	ISML-ITMT	9.00	16/750, *Q*, 4/625	81/625, *A.C.* to *R.T.*	1.67	48/860, *Q*	40/800	1.00

Notes: *A.C.* to *R.T.* = Air cooled to room temperature.
Q = Cold water quenched.
F.C. = Furnace cooled.
All rolling carried out without intermediate reheats except for rolling at 800°F.

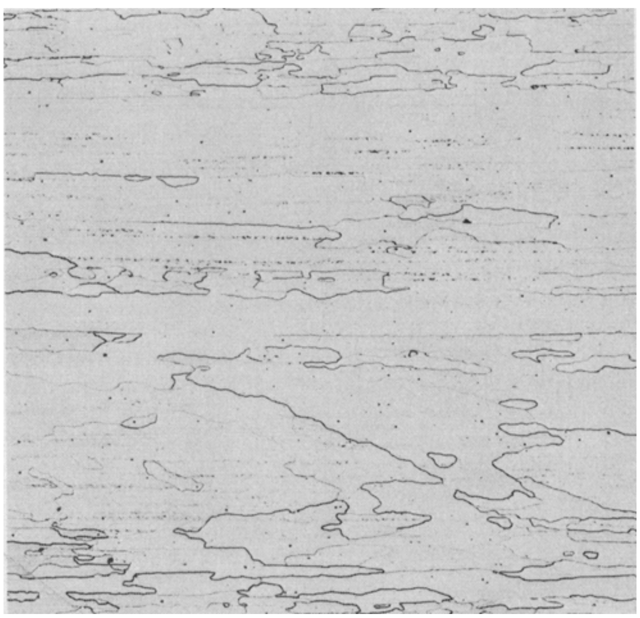


Fig. 4—Microstructure of 7075 given Treatment 3 (Conventional Processing) in the T6 temper. Longitudinal section. Magnification 100 times. Keller's etch.

technique and the ISML-ITMT technique are shown in Figs. 2 to 5. The corresponding tensile properties of the materials in the T6 temper are presented in Table II.

It can be seen that the experimental techniques produced AR + HR sheet material (Figs. 2(*b*) and 3(*b*)) that has grain sizes finer than that produced using conventional processing (Fig. 4). Also, it can be seen from Table II that the experimentally processed material has equivalent strength and significantly greater reduction in area than the conventionally processed sheet.

With regard to the experimental treatments themselves, the grain size of the material processed according to Treatment 1 is much finer than that of material processed according to Treatment 2 (Figs. 2 and 3). This is especially true in the AR condition. The reason for the difference in the grain sizes will be discussed later.

The microstructures and tensile properties of the materials produced using the ISML-ITMT method are shown in Fig. 5 and Table II, respectively. The important result is that the ISML-ITMT sheet has a finer grain size, equivalent strength and higher elongation and reduction in area than the conventionally processed

Table II. Long Transverse Tensile Properties of Conventional and ITMT Processed 7075-T6 Sheet (0.160 in. Thick)

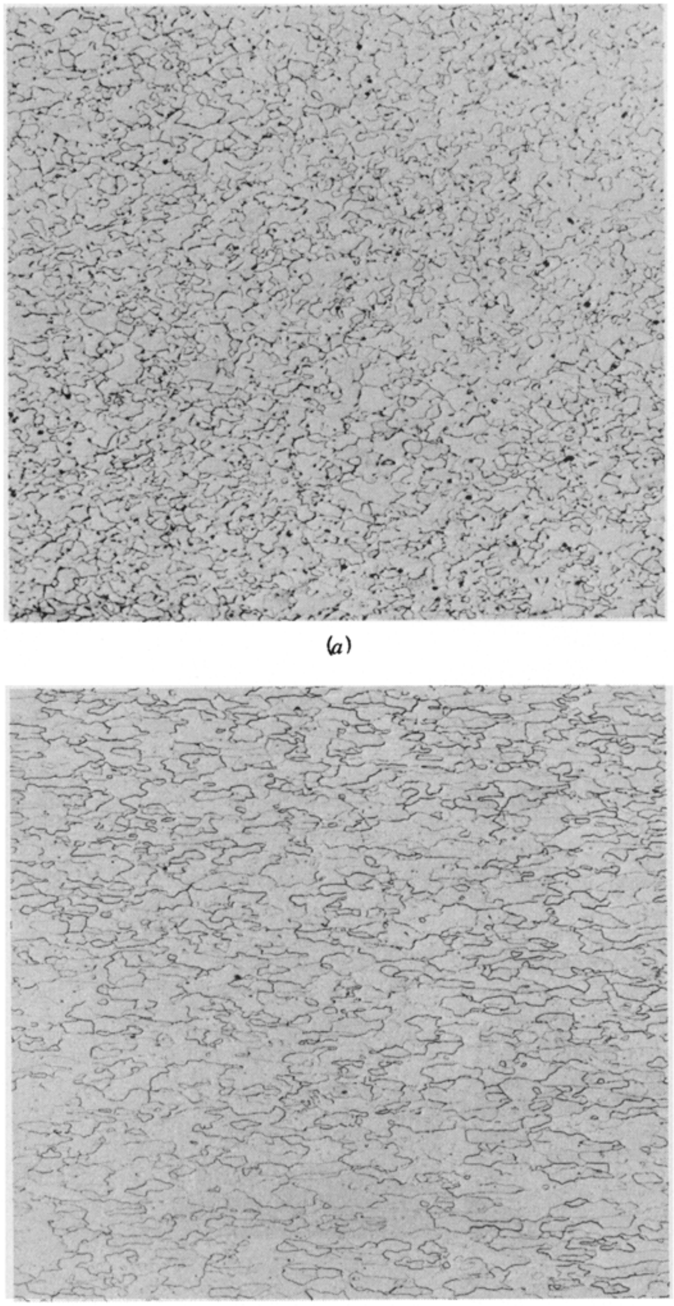
Treatment No.	Process	Condition	Y.S.(0.2 pct off-set) ksi	U.T.S., ksi	E in 0.45 in. pct	R.A., pct
1	Experimental (FA-ITMT)	*AR* + *HR*	71.8	84.1	14.9	42.6
2	Experimental	*HR*	70.7	82.9	14.6	38.3
3	Conventional	*HR*	69.8	83.3	12.8	31.1
4	ISML-ITMT	*AR* + *HR*	71.0	84.0	14.6	44.5

T6 = 1 h/900°F, cold water quenched, naturally aged 5 days, 24 h/250°F.
HR = Hot rolled.
AR = As-recrystallized.

sheet. These results are in agreement with the work of DiRusso *et al.*[7-9]

On comparing the experimental treatments with the ISML-ITMT technique, two general points are evident. The first is that experimental Treatment No. 1 produced sheet which was equivalent to ISML-ITMT processed material. Specifically, it can be seen from Figs. 2 and 5 that the grain sizes of the materials produced by the two processes are essentially the same. Also, the tensile properties of the experimentally processed material and the ISML-ITMT material show the same significant improvement in ductility (Table II). The second point in this comparison is that the fine grain size achieved using Treatment No. 1 shows that it is also possible to produce a fine grain recrystallized structure in 7075 without maintaining the Cr in supersaturated solid solution in the Al-rich matrix prior to the recrystallization homogenization step. Thus, it appears that Treatment No. 1 is important in that it forms the basis of another ITMT method (hereafter referred to as the Frankford Arsenal ITMT process or FA-ITMT), one in which the Cr is precipitated out of solution by a high temperature homogenization prior to the initial deformation step.

Since FA-ITMT processing produced a fine grain structure comparable to that produced using ISML-ITMT, it appears that there are other structural factors besides the Cr distribution that are important in determining whether or not a fine grain recrystallized structure can be produced in 7075. The obvious structural parameter that should be studied is the distribution of the major alloying elements, Zn, Mg and Cu prior to the initial deformation and recrystallization step. The results of electron probe work to investigate this distribution are shown in Figs. 6 to 8. Regarding the FA-ITMT and ISML-ITMT techniques, both of which produce a fine grain recrystallized structure, it can be seen from Figs. 6 and 8 that the Zn, Mg and Cu are present as coarse precipitates prior to the initial deformation step. In contrast, in Treatment No. 2, which produced a grain structure that was much larger than that produced using either the FA-ITMT or ISML-ITMT processes, the Zn, Mg and Cu are in solid solution in the Al-rich matrix prior to the initial deformation step (Fig. 7). (It should be pointed out that in this work, no attempt was made to resolve the distribution of the Zn, Mg and Cu on a finer scale than is possible using optical microscopy.) Thus, the present work shows that the distribution of the major alloying elements, Zn, Mg and Cu has a significant effect on the recrystallized grain size of 7075. Also, the work shows that by control of the distribution of the Zn, Mg and Cu, fine grained 7075 can be produced independent of the distribution of the Cr.



(a)

(b)

Fig. 5—Microstructures of 7075 given Treatment 4 (ISML-ITMT). Longitudinal Sections. Magnification 100 times. Keller's etch. (*a*) As-recrystallized and (*b*) Recrystallized, hot rolled and T6.

Plate

This section is concerned with applying the ISML-ITMT and FA-ITMT processes to thick products of 7075, *i.e.*, plate. In this work, the effect of varying the degree of initial deformation in both ITMT pro-

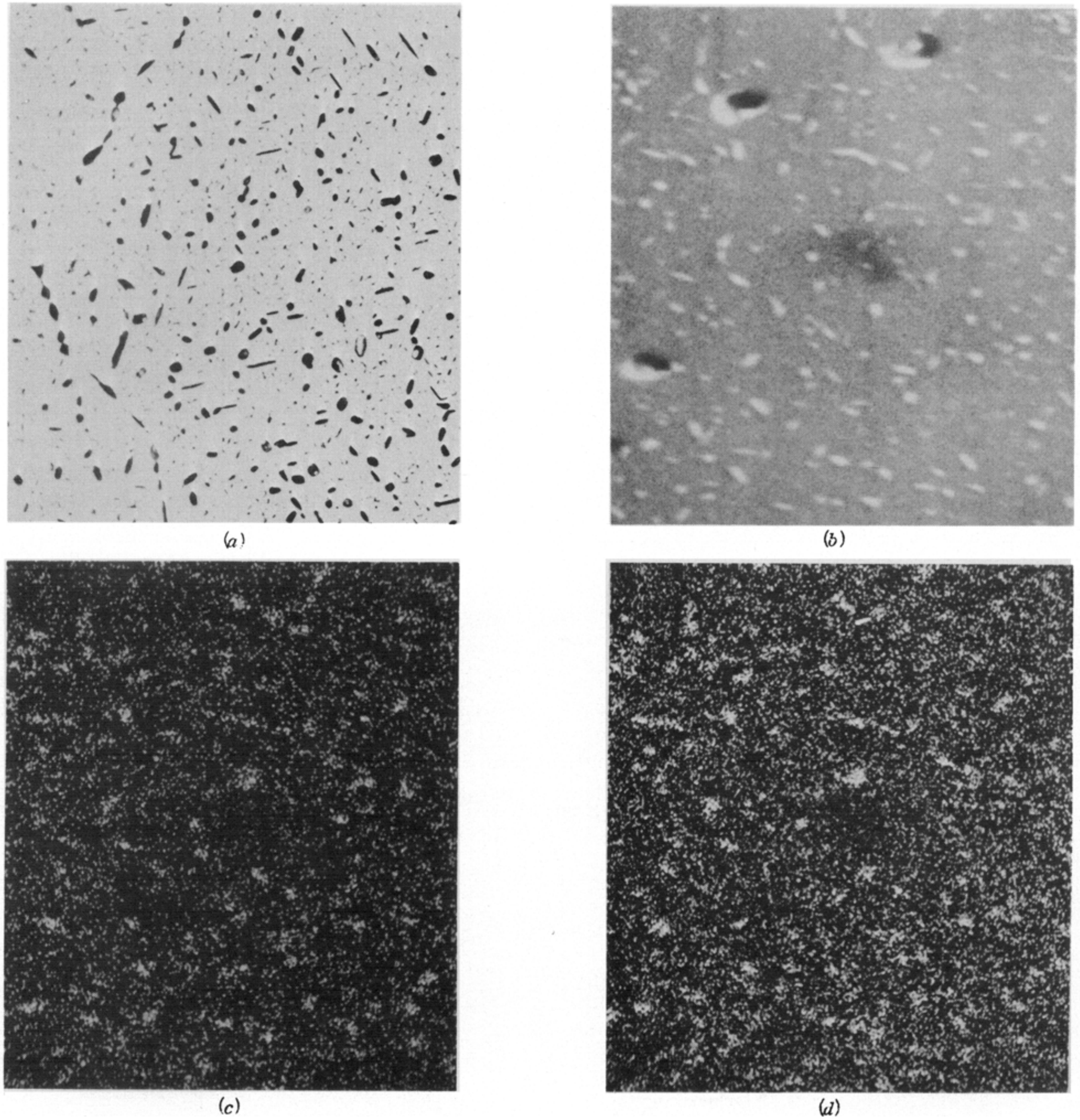


Fig. 6—Microstructures of 7075 given the homogenization step prior to initial deformation in Experimental Treatment 1 (FA-ITMT). (*a*) Keller's etch, (*b*) Backscattered electron image, (*c*) X-ray picture of Cu distribution and (*d*) X-ray picture of Zn distribution. Magnification 500 times.

cesses on the grain structure and mechanical properties of 0.4 and 0.7 in. thick plate was examined. These results are reported in the following section on wedge studies. The subsequent section describes the application of both ITMT processes to 1 in. thick plate.

WEDGE STUDIES

The long transverse tensile properties of the AR (0.7 in. thick) and AR + HR (0.4 in. thick) plates processed to the T6 temper by FA-ITMT, by ISML-ITMT and by conventional techniques are shown in Table III for various degrees of deformation prior to recrystallization in the wedge-shaped billet. Also included in this Table are the grain sizes of the materials.

The yield strength and ultimate tensile strength of all the materials increase slightly with increasing degree of deformation. However, for a given degree of deformation, the yield and ultimate tensile strengths of all the materials vary only to a small extent despite large differences in grain size. Thus, it appears that the grain size has only a minor effect on the strength of these alloys in the fully aged condition (T6 temper). The slight increase in strength with decreasing grain size can be seen from Fig. 9 which is a plot of the yield strength as a function of the reciprocal of the square root of the grain diameter $D_{\perp}$. A similar relationship was observed between yield strength and the reciprocal of the square root of the grain diameter $D_{\parallel}$. The slight grain size dependence of the yield strength

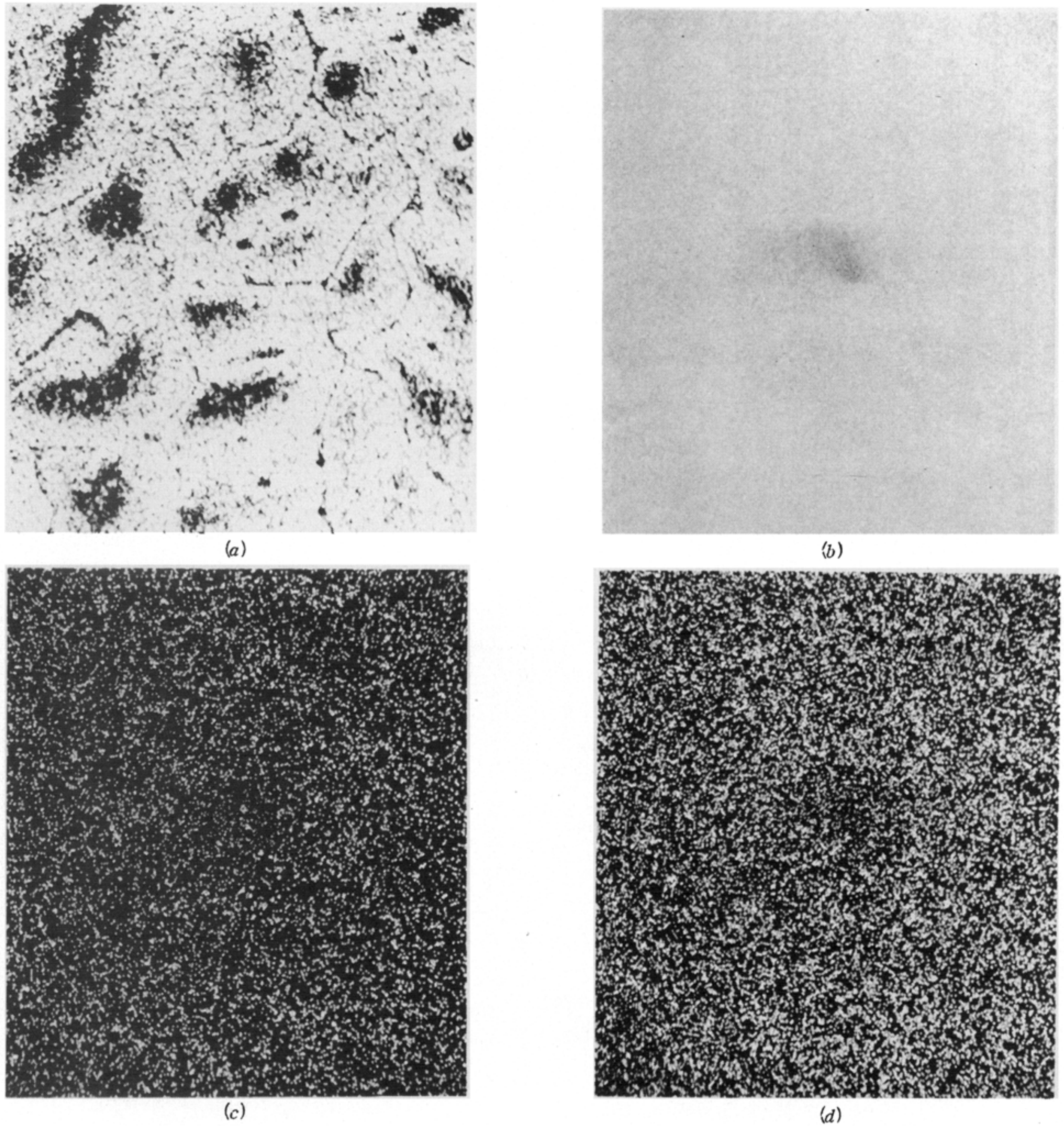
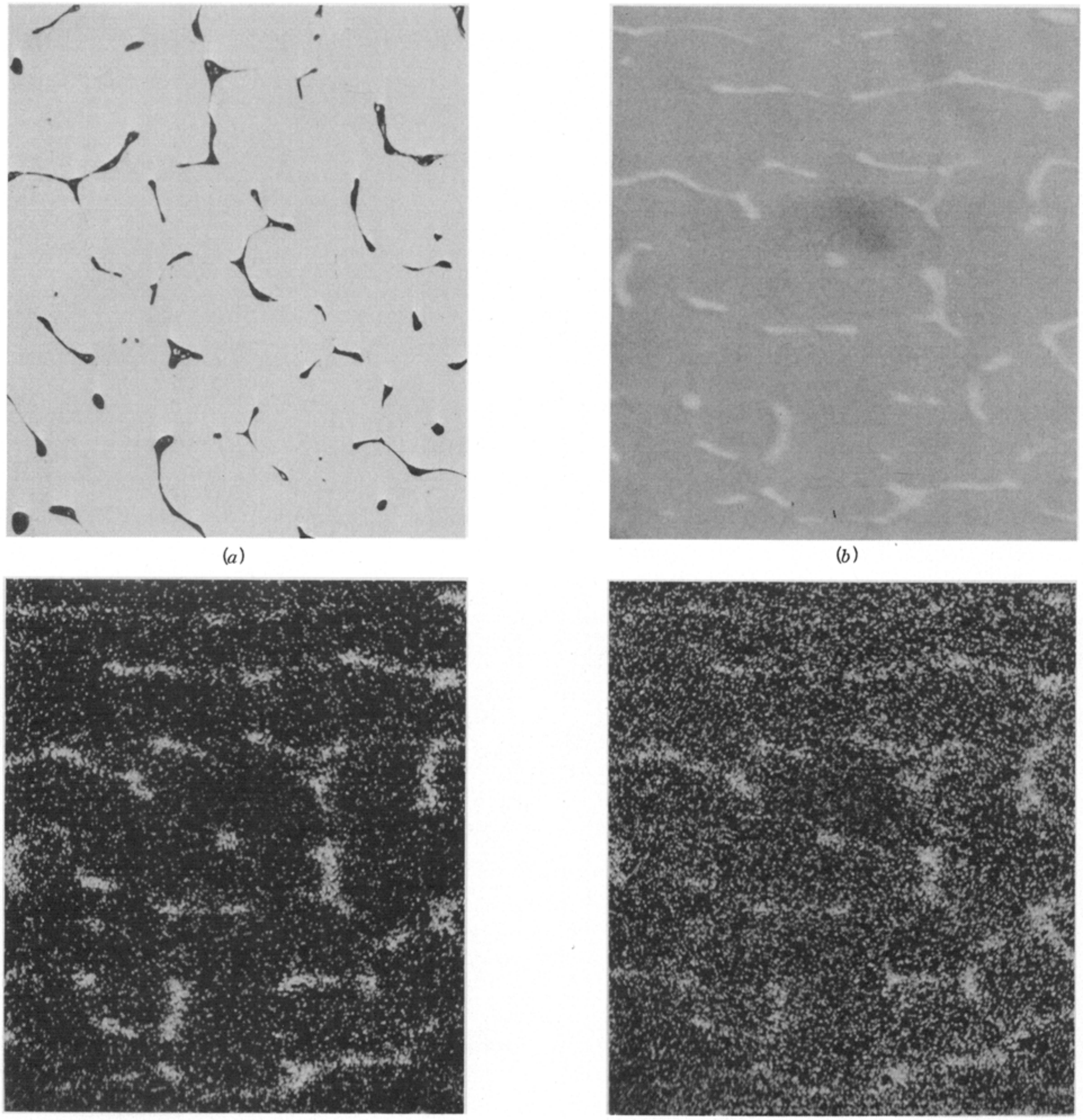


Fig. 7—Microstructures of 7075 given the homogenization step prior to initial deformation in Experimental Treatment 2. (*a*) Keller's etch, (*b*) Backscattered electron image, (*c*) X-ray picture of Cu distribution and (*d*) X-ray picture of Zn distribution. Magnification 500 times.

is contrary to the usual strengthening effect of a fine grain size in pure metals and solid solution alloys. The possible explanation may be the fact that the fine grain size in the ITMT processed materials, (15 to 20 microns; see Table III) although much finer than that of conventionally processed material, is still considerably larger than the spacing of the hardening particles (G.P. zones and intermediate precipitates) which is of the order of angstrom units. Thus, the movement of dislocations is essentially unaffected by the grain size in ITMT processed 7075. A similar explanation has been offered for the small effect of grain size on the yield strength of 2024-T4.[11] A final point with regard to strength is that the strengths of the AR and the AR + HR materials are equal at a given initial degree of deformation.

The elongation and reduction in area of the conventionally processed 0.4 and 0.7 in. thick plates increase only slightly with increasing degree of deformation whereas these quantities significantly increase in the ITMT processed materials (Table III). The increase is especially pronounced for degrees of deformation of at least 50 pct; on the basis of metallographic examination this level corresponds to the degree of deformation needed to produce a fine grain size after recrystallization. This pronounced dependence of ductility on grain size in 7075-T6 can be readily seen from Fig. 9. For a given ITMT treatment at a given degree of initial de-



(a) (b) (c) (d)

Fig. 8—Microstructures of 7075 given the homogenization step prior to initial deformation in Treatment 4 (ISML-ITMT). (a) Keller's etch, (b) Backscattered electron image, (c) X-ray picture of Cu distribution and (d) X-ray picture of Zn distribution. Magnification 500 times.

formation, the ductility of the AR + HR material is higher than that of the AR material; however, this may be fortuitous since the thicknesses of the AR plate and the AR + HR plate materials were different.

1 IN. THICK PLATE

The initial work showed that the degree of deformation necessary to produce a fine grain structure in the 0.4 and 0.7 in. thick plate, *i.e.*, 60 pct, was not sufficient to produce a fine grain structure in the 1 in. thick plate. Hence, the deformation was increased to 81 pct. Also, in order to induce more stored energy of cold work in the plates, lower deformation temperatures were used to produce the 1 in. thick plates than were used to produce the sheets. Specifically, in the FA-ITMT process, deformation temperatures of 400° and 500°F (Treatments 8 and 9, Table I) were used and in the ISML-ITMT process, deformation temperatures of 550° and 625°F were used (Treatments 10 through 12, Table I). The grain structures of the AR ITMT and the AR + HR ITMT 1 in. thick plates are shown in Figs. 10 to 14.

It can be seen that the grain size of the AR FA-ITMT material (Fig. 10) is finer than that of the commercial 7075-T651 (Fig. 15). There appears to be a duplex structure in the AR ISML-ITMT 1 in. thick plates (Figs. 11 and 12). However, the overall grain structure is also finer than that of the commercial 7075-T651. Although the duplex structure is not present in the FA-

Table III. Long Transverse Tensile Properties and Grain Size of Conventional and ITMT Processed 7075-T6 Plate (Wedge Studies)

As-Recrystallized 0.7 in. Thick Plate							As-Recrystallized + Hot Rolled 0.4 in. Thick Plate						
					Grain Size							Grain Size	
Deformation pct	Y.S. (0.2 pct offset) ksi	U.T.S., ksi	E in 1 in. pct	R.A., pct	$D_\perp, \mu$	$D_\parallel, \mu$	Deformation pct	Y.S. (0.2 pct offset) ksi	U.T.S., ksi	E in 1 in. pct	R.A., pct	$D_\perp, \mu$	$D_\parallel, \mu$
FA-ITMT													
20	69.9	81.6	14.7	24.6	74.5	63.0	20 + 40	71.6	81.9	13.7	25.5	59.0	114.4
30	69.9	81.4	15.7	32.8			30 + 40						
40	70.4	81.6	17.1	33.5	20.4	36.9	40 + 40	70.6	81.2	16.0	33.3		
50	70.7	81.8	16.6	33.3	16.7	35.8	50 + 40	70.6	81.5	16.0	34.0	17.7	54.5
60	71.1	81.9	16.4	37.9			60 + 40	71.7	82.7	19.4	37.9		
68	70.7	82.1	17.4	31.6	14.9	28.3	68 + 40	70.9	82.8	19.6	40.7	21.3	55.5
Conventional													
20	66.9	76.1	15.5	27.0	111.7	298.0	20 + 40	68.7	77.5	12.0	27.4	50.8	149.0
60	70.3	78.9	13.0	28.0			60 + 40	70.1	79.1	16.0	31.8		
67	74.5	81.2	12.0	24.0	61.0	119.1	67 + 40	69.6	79.0	16.0	28.4	28.6	94.1
ISML-ITMT													
20	69.0	80.6	15.6	26.7	35.0	40.6	20 + 40	70.5	81.4	13.9	31.3	21.6	48.8
30	69.9	81.4	16.0	25.3	29.2	45.1	30 + 40	70.9	82.2	18.0	29.3		
40	70.1	81.6	16.8	27.9	22.9	28.8	40 + 40	70.7	82.4	18.4	38.7		
50	71.7	82.3	17.1	41.5	18.2	24.5	50 + 40	71.0	82.8	19.2	42.0	15.6	38.7
58.5	70.7	82.4	19.1	35.4	15.2	24.4	60 + 40	71.4	82.8	19.4	43.8		
70	70.7	82.4	19.0	30.7	15.3	27.9	70 + 40	71.4	82.9	20.0	47.4	13.3	37.5

T6 = 3 h/900°F, cold water quenched, naturally aged 5 days, 24 h/250°F.

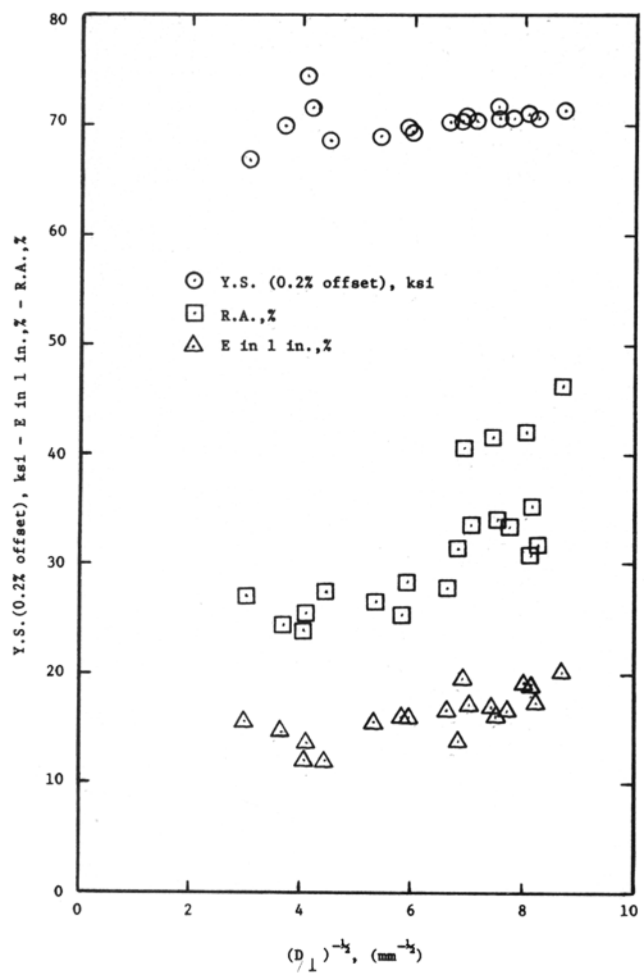


Fig. 9—The mechanical properties of 7075-T6 as a function of the reciprocal of the square root of the grain size measured from a longitudinal section in a direction perpendicular to the rolling direction.

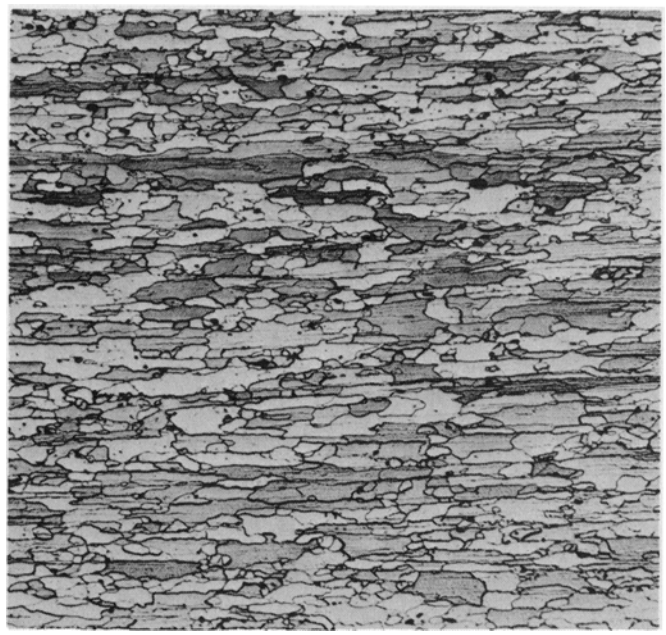


Fig. 10—Microstructure of AR FA-ITMT 7075 plate (1 in. thick) produced following Treatment 8 in Table I and given the T6 temper. Longitudinal section. Magnification 100 times. Keller's etch.

ITMT material, the grain size is somewhat larger than that in the fine grained areas of the duplex structures of the ISML-ITMT material. The reason for this may be related to the differences in the two ITMT processes or to differences in the temperatures of working. It was found that in the ISML-ITMT process, increasing the recrystallization temperature to 960°F eliminated the duplex structure and produced fine equiaxed grains (Fig. 16). Although a direct thermal treatment at 960°F could produce incipient melting, the possibility of using recrystallization temperatures between 860° and 960°F

Fig. 11—Microstructure of AR ISML-ITMT 7075 plate (1 in. thick) produced following Treatment 10 in Table I and given the T6 temper. Longitudinal section. Magnification 100 times. Keller's etch.

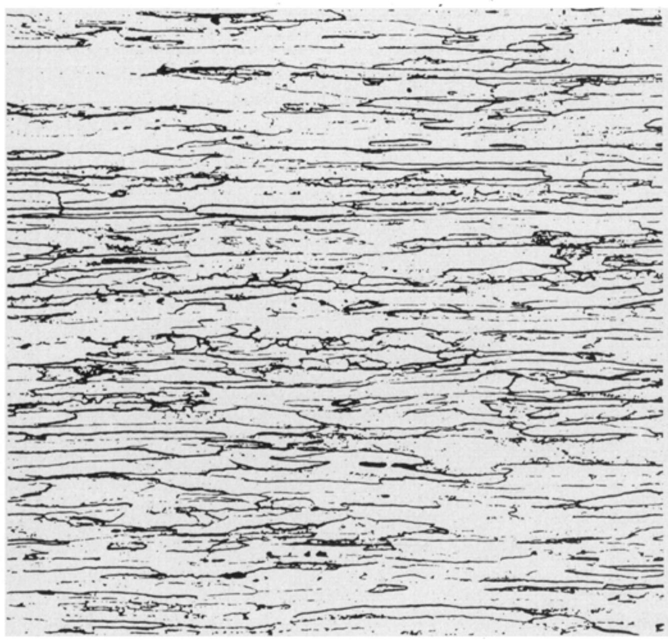


Fig. 13—Microstructure of AR + HR FA-ITMT 7075 plate (1 in. thick) produced following Treatment 9 in Table I and given the T6 temper. Longitudinal section. Magnification 100 times. Keller's etch.

Fig. 12—Microstructure of AR ISML-ITMT 7075 plate (1 in. thick) produced following Treatment 11 in Table I and given the T6 temper. Longitudinal section. Magnification 100 times. Keller's etch.

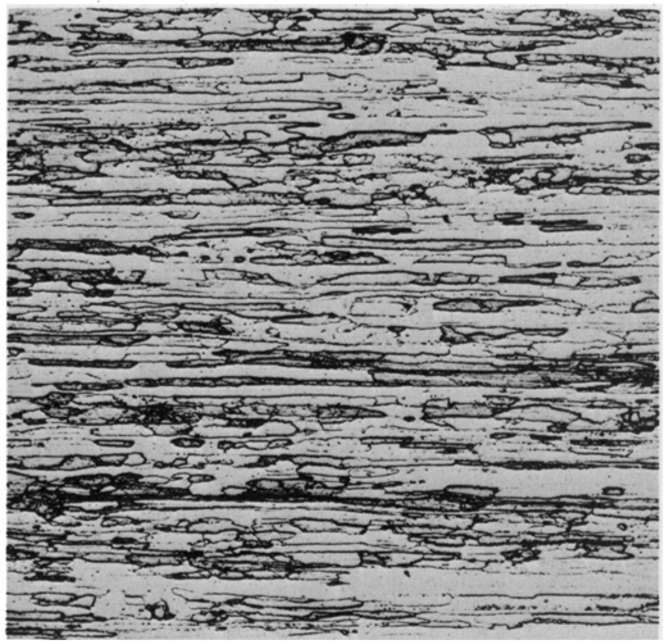


Fig. 14—Microstructure of AR + HR ISML-ITMT 7075 plate (1 in. thick) produced following Treatment 12 in Table I and given the T6 temper. Longitudinal section. Magnification 100 times. Keller's etch.

should be examined. With regard to the AR + HR condition, there is no indication of a duplex structure in either the FA-ITMT or ISML-ITMT plates (Figs. 13 and 14). Also there appear to be no significant differences between the grain structures of the materials produced using either ITMT process although both have a finer grain size than conventionally processed material.

The tensile properties of the FA-ITMT and ISML-ITMT AR and AR + HR 1 in. thick plate in the T6, T76, and T73 tempers are shown in Table IV. As with sheet and 0.4 and 0.7 in. thick plate, the ITMT 1 in. thick plates have equivalent strength and significantly better elongation and reduction in area than conventionally processed plate. In addition, the benefits to be derived from combining ITMT with the concepts of homogenization can be deduced from Table IV. Specifically, in the longitudinal direction the conventionally processed commercial purity material in the T6 temper had an elongation of 10 pct and a reduction in area of about

14 to 17 pct. By employing homogenization concepts but still using conventional processing, the elongation was increased to about 14 pct and the reduction in area to about 21 pct. Finally, by applying ITMT processing to the homogeneous material, the elongation was increased still further to about 18 pct and the reduction in area was increased to the order of about 30 pct.

It should be pointed out that although high purity 7075 ITMT 1 in. thick plate has significantly better mechanical properties than conventionally processed material of either commercial or high purity, the optimum grain morphology of the ITMT material may not have yet been achieved. If this is the case, even more significant improvements may be possible. In addition, it is felt that a fine grain structure has the potential of significantly improving such secondary properties as fracture toughness, stress corrosion resistance and fatigue strength. Measurements are in progress to verify this. Finally, it appears that by combining homogenization concepts with ITMT and FTMT processing, a potential method is now available for producing new alloys and tempers which will have significantly higher strength and ductility than commercially available aluminum alloys. To this end, the research program at Frankford Arsenal includes extending the concepts of homogenization, ITMT and FTMT to other 7000 series alloys such as 7075-Zr, 7050 and X7007 and such 2000 series alloys as 2219 and 2024. These results will be reported in a later paper.

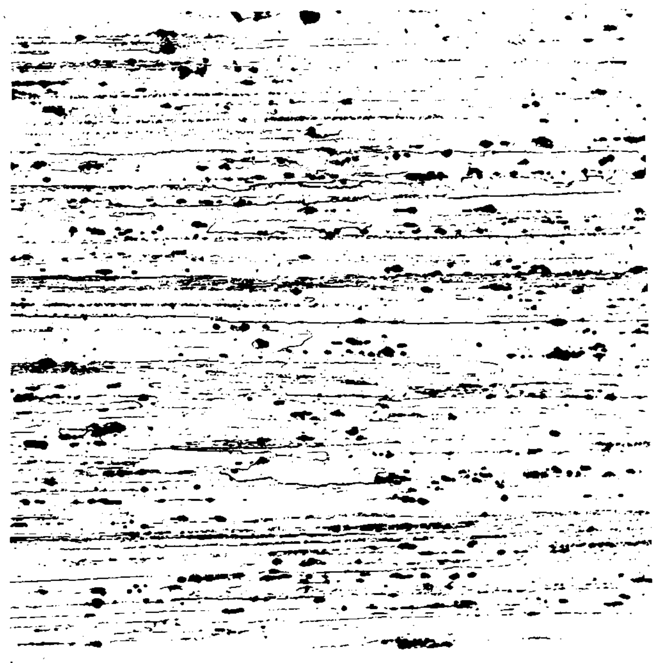
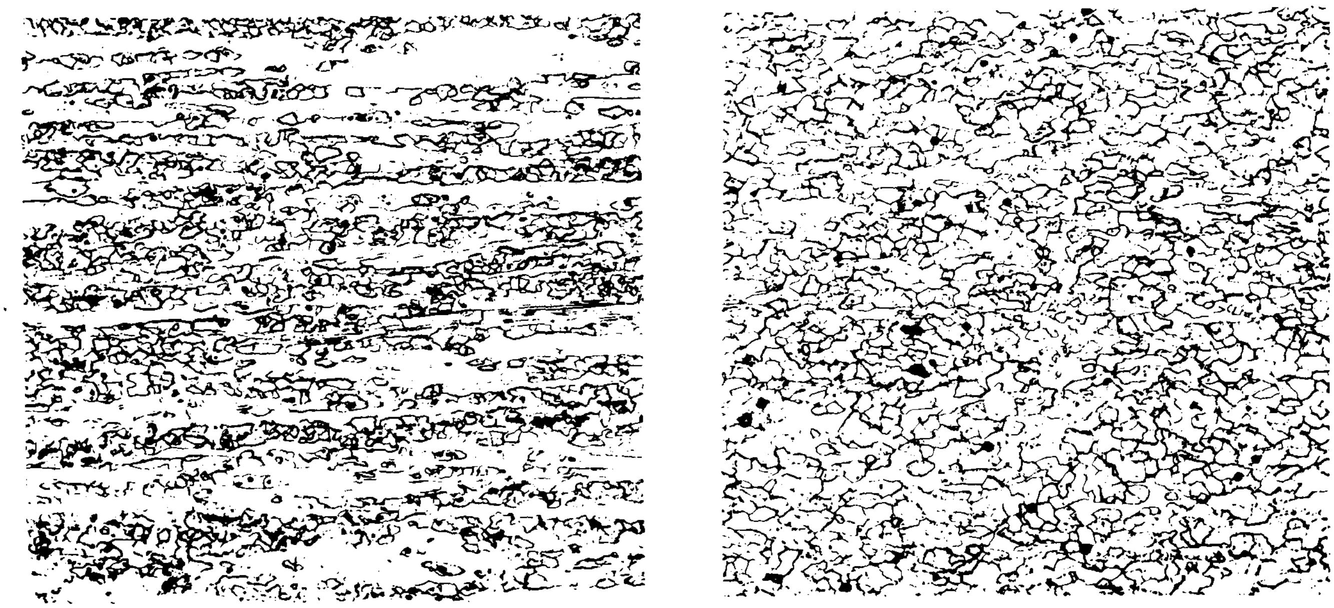


Fig. 15—Commercial 7075-T651 plate (1 in. thick). Longitudinal section. Magnification 100 times. Keller's etch.

CONCLUSIONS

1) The recrystallization of 7075 alloy into a fine grained structure can be controlled by the distribution of the Cr in the microstructure as well as by control of the distribution of the major alloying elements, Zn, Mg and Cu.

2) A new ingot processing technique, FA-ITMT, was developed for producing fine grained 7075 sheet and plate. In this method, the ingot is given a high temperature homogenization to precipitate the Cr and is then slowly cooled to precipitate the Zn, Mg and Cu as coarse particles. The ingot is then worked at a low temperature, recrystallized and homogenized. The material can be utilized in this condition with fine equiaxed grains or it can be conventionally worked to produce fine elongated grains.



(*a*) **860°F** (*b*) **960°F**

Fig. 16—Microstructure of AR ISML-ITMT 7075 plate (1 in. thick) produced following Treatment 10 except (*a*) recrystallized at 860°F for 24 h and (*b*) recrystallized at 960°F for 24 h and water quenched. Magnification 100 times. Keller's etch.

Table IV. Tensile Properties of Conventional and ITMT Processed 7075 Plate (1.0 in. Thick) in the T6, T76 and T73 Tempers

			Longitudinal				Long Transverse				
Treatment No.	Process	Condition	Y.S. (0.2 pct offset) ksi	U.T.S., ksi	E in 2 in. pct	R.A., pct	Y.S. (0.2 pct offset) ksi	U.T.S., ksi	E in 2 in. pct	R.A., pct	E.C., pct IACS
					T6 Temper						
Comm. Purity*	Conventional	*HR*	76.4	85.2	10.0	14-17†	72.8	82.5	9.5	14-16†	
High Purity ‡	Conventional	*HR*	74.1	84.2	13.7	21.1	75.8	86.0	12.5	20.5	
8	FA-ITMT	*AR*	73.7	83.3	18.0	29.8	73.9	83.0	19.0	35.1	33.5
9	FA-ITMT	*AR + HR*	73.4	82.7	15.7	31.0	72.9	82.1	17.8	40.8	32.1
10	ISML-ITMT	*AR*	74.6	83.6	17.5	29.4	73.7	83.2	18.2	29.6	34.0
11	ISML-ITMT	*AR*	73.8	83.6	17.0	27.8	76.4	86.1	16.0	25.8	33.7
12	ISML-ITMT	*AR + HR*	76.4	85.7	16.0	32.0	73.8	82.6	16.8	38.9	31.3
					T76 Temper						
Comm. Purity ¶	Conventional	*HR*	68.0	78.0	12.0						
8	FA-ITMT	*AR*	68.9	78.1	16.3	44.0	69.5	78.6	15.5	39.5	38.6
9	FA-ITMT	*AR + HR*	69.5	79.0	17.5	48.4	67.2	76.3	15.3	43.3	39.7
10	ISML-ITMT	*AR*	71.9	80.2	16.5	43.8	72.1	80.1	14.8	37.3	37.9
11	ISML-ITMT	*AR*	71.9	80.5	15.5	42.0	72.5	79.8	14.5	35.9	38.1
12	ISML-ITMT	*AR + HR*	70.5	79.7	14.3	42.4	68.6	77.2	14.0	38.9	38.0
					T73 Temper						
Comm. Purity*	Conventional	*HR*	66.3†	76.7†	12.0†	29.0†	64.6†	74.9†	10.5†	20.0†	
8	FA-ITMT	*AR*	67.9	76.7	16.5	48.5	66.5	75.6	16.0	45.1	40.6
9	FA-ITMT	*AR + HR*	64.3	74.0	17.0	49.6	64.6	74.2	15.4	42.9	40.5
10	ISML-ITMT	*AR*	67.4	76.4	16.5	50.0	66.6	75.5	14.5	38.4	41.2
12	ISML-ITMT	*AR + HR*	65.9	75.4	16.1	51.2	65.3	74.5	15.1	41.6	40.0

T6 Temper = 3 h/900°F, cold water quenched, naturally aged 5 days, 24 h/250°F.
T76 Temper = 3 h/900°F, cold water quenched, naturally aged 5 days, 4 h/250°F + 18 h/325°F.
T73 Temper = 3 h/900°F, cold water quenched, naturally aged 5 days, 6 h/225°F + 8 h/350°F.
HR = Hot rolled.
AR = As-recrystallized.
*J. G. Kaufman and M. Holt, "Fracture Characteristics of Aluminum Alloys", Paper No. 18, Alcoa Research Labs, 1965.
†1.375 in. thick plate.
‡Homogenized 3/4 in. thick plate.
¶R. A. Schultz, "Alcoa Alloys 7075-T76 & 7178-T76", Alcoa Green Letter, January 1970.

3) Fine grained 7075 sheet and plate produced by the FA process have equivalent strength and significantly better elongation and reduction in areas than conventionally processed material in the T6, T76 and T73 tempers.

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