

[54] **TEAR RESISTANT SHEET AND PLATE AND METHOD FOR PRODUCING**

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[51] Int. Cl. **C22f 1/04**

[58] Field of Search **148/11.5 A, 12.7, 32, 32.5, 148/34**

References Cited

UNITED STATES PATENTS

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3,133,839	5/1964	Thomas	148/11.5 A
3,198,676	8/1965	Sprowls et al.	148/159
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[57] ABSTRACT

An aluminum base alloy of the aluminum-zinc-magnesium-copper-chromium type with specially controlled composition limits is provided as a sheet or plate type product having the high strength and good resistance to stress corrosion cracking normally associated with this type of alloy but also having exceptional resistance to tearing. Certain prescribed fabrication procedures including thermal treatments are preferably followed in producing the improved product.

20 Claims, 3 Drawing Figures

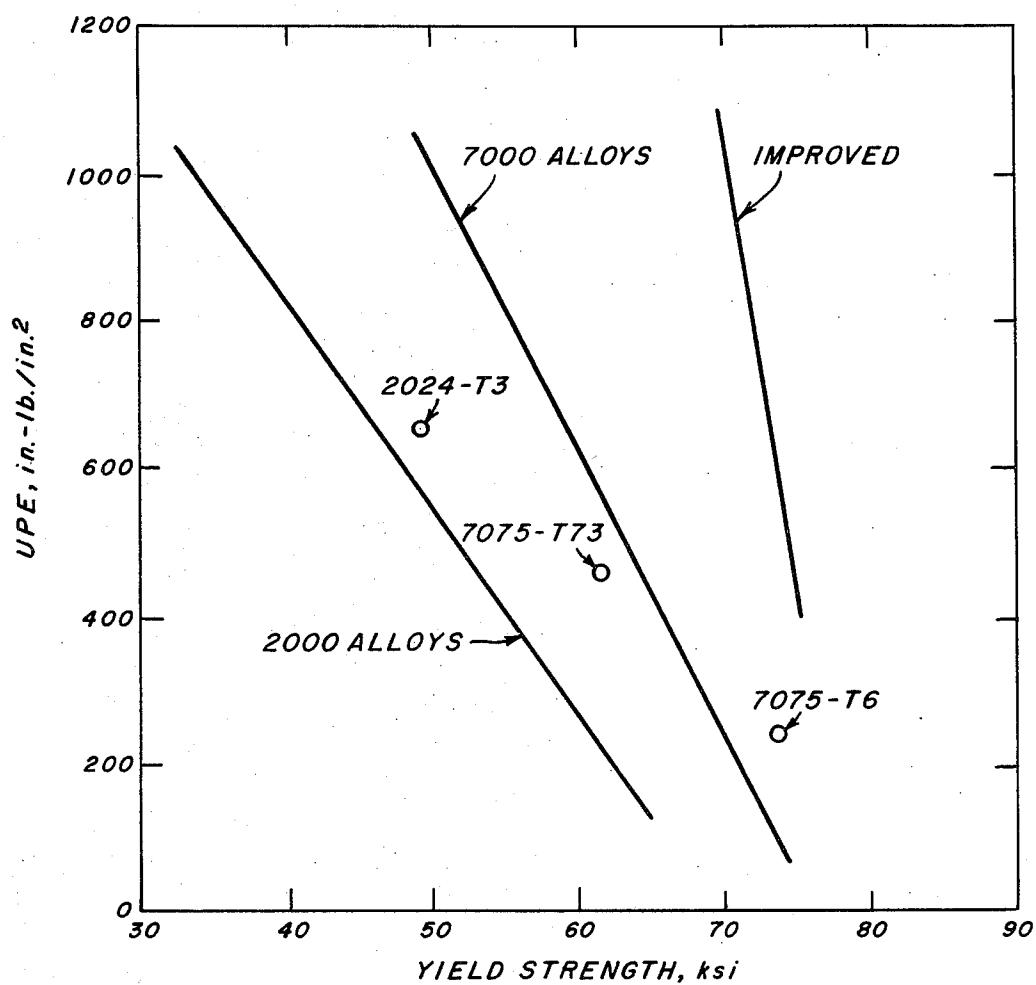


FIG. 1.

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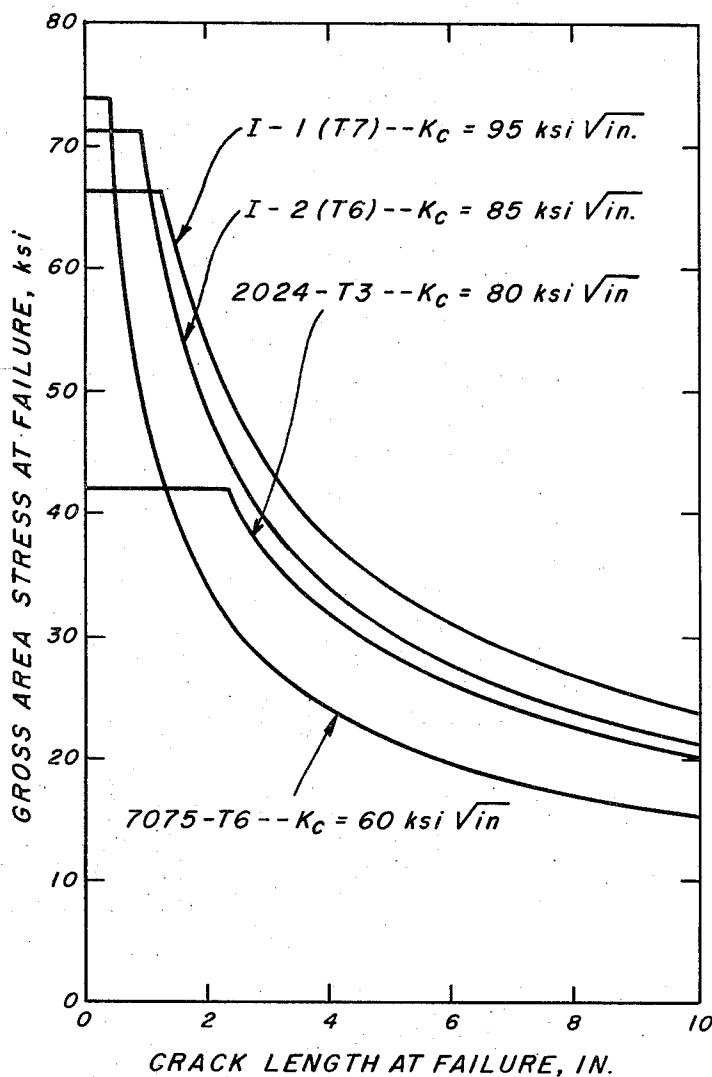


FIG. 3.

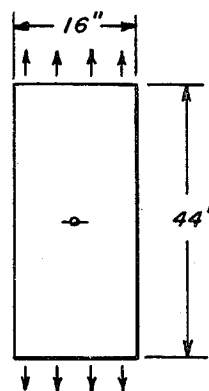


FIG. 2.

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TEAR RESISTANT SHEET AND PLATE AND METHOD FOR PRODUCING

This is a continuation of application Ser. No. 58,337, filed July 27, 1970, now abandoned.

This invention relates to the production of improved sheet including the thermal treatment thereof and to the new sheet product.

BACKGROUND OF THE INVENTION

Aluminum alloys containing 3.5 to 8% zinc, 1.5 to 4% magnesium, 0.75 to 2.5% copper are known for their high strength to weight ratio which renders them highly suited for use in applications such as structural components for aircraft. Alloy 7075 is an example of this type alloy and has achieved widespread use in aircraft because of its high strength and other desirable properties. Alloy 7075 contains 5.1 to 6.1% zinc, 2.1 to 2.9% magnesium, 1.2 to 2% copper, 0.18 to 0.40% chromium, the balance being aluminum and, as impurities, up to 0.7% iron, 0.5% silicon, 0.3% manganese and 0.2% titanium. In sheet gages, 7075 develops typical tensile and yield strength levels of, respectively, 83 ksi and 73 ksi in the high strength, or T6, temper in the unclad condition. Also, both bare and clad 7075-T6 sheet are resistant to stress corrosion cracking. For certain fracture-critical applications such as wing or pressurized fuselage skin, however, the aircraft industry is desirous of improving the tear resistance and toughness of this alloy. The tear resistance of 7075 type sheet is improved by the application of a two-step aging treatment as described in U.S. Pat. No. 3,198,676, but at a 15% loss in strength, although the extent of the increase in tear resistance falls short of current needs.

Other aluminum base alloys have better tear resistance than 7075, but they have lower strength. For example, alloy 2024-T3 (nominal 4.5% copper, 0.6% manganese and 1.5% magnesium) is used in aircraft despite its relatively low strength of 65 tensile and 45 ksi yield because of its very good tear resistance. The aircraft designers, however, need a material having both high strength and high tear resistance although, to date, this has been quite elusive on a commercially repeatable scale.

DESCRIPTION

In practicing the invention high strength and tear resistance properties are achieved along with high resistance to stress corrosion cracking by carefully controlling the composition and the fabrication of sheet products of an alloy similar to the 7075 type described. The composition in accordance with the invention is an aluminum alloy consisting essentially of, by weight, 5.2 to 6.2% zinc, 1.9 to 2.5% magnesium, 1.2 to 1.9% copper, 0.18 to 0.25% chromium, the balance being aluminum and incidental elements and impurities. It is important that impurities be limited such that the following maxima apply: Fe 0.12%, Si 0.10%, Mn 0.06%, Ti 0.06%, other elements each 0.05%, combined 0.15%. We have found that in order to achieve the desired level of toughness the foregoing composition limits must be carefully followed, for instance, increasing the magnesium content to a level of only 2.6 to 2.7% markedly decreases the toughness.

The foregoing special composition limits in combination with special high temperature thermal treatments where the temperatures exceed those normally employed in alloys of the 7075 type together with effective

amounts of strain hardening all cooperate in achieving the desired markedly improved toughness and tear resistance in a sheet or plate product of very high strength. Normally 7075 type sheet or plate is not heated above 930°F for any purpose, although it has now been found that unique properties are obtained if this previous maximum is exceeded by heating to at least 940°F, preferably between 950° and 1000°F. Preferably the fabrication cycle includes two such exposures, one at the solution heat treating stage and one somewhat earlier, during or before hot rolling. The improved sheet product exhibits (1) a low volume fraction of intermetallic phases containing Fe or Si of less than 0.7 percent total, (2) E phase $Al_{12}Mg_2Cr$ precipitate particles having a median size of 1400 Å or larger together with (3) a fine grain size. These combine to impart the improvement.

In this description reference is made to the drawings in which:

FIG. 1 is a graph plotting average yield strength versus tear resistance for the improved and for comparison sheet products;

FIG. 2 is a plan view of one type of tear testing specimen; and

FIG. 3 is a graph plotting gross area stress versus crack length for the improved and for comparison sheet products as determined from tear tests using specimens of the type shown in FIG. 2.

Perhaps the best way to appreciate the type of improvement here described is to refer to FIG. 1 which plots tensile yield strength versus unit propagation energy for sheet products in 2000 series alloys, Al-Cu systems, and 7000 series alloys, Al-Zn systems, together with the improved sheet product. The plots are based on averages of longitudinal and transverse properties. As explained later, unit propagation energy is one measure of toughness, the higher the UPE, the tougher and more tear resistant the material. The lines in FIG. 1 depict the mean performance levels for the various sheet alloys for ready comparison and certainly shows clearly that the improved sheet offers the highest combination of strength and toughness. For instance 2024 sheet in the T3 temper which has the highest toughness for this alloy, exhibits a UPE level of over 600 which is considered quite tough as it certainly exceeds a 400 UPE level which is considered a good indication of a high toughness material. However note that the yield strength is only 50 ksi which certainly cannot be considered high by modern standards. On the other hand alloy 7075 sheet in the T73 temper, a tough temper for this material, exhibits much better strength but also a much lower UPE than 2024 sheet. This typifies the problem facing the art which could provide sheet having high toughness or high strength but not both. In direct contrast, FIG. 1 shows how the improved sheet product changes the prior situation and exhibits very high toughness at the highest strength levels. The improved sheet can achieve UPE levels exceeding 1000 in-lb/in² at yield strength levels over 70 ksi which has not previously been considered possible in an aluminum alloy sheet, especially in a relatively economical and commercially useful sheet product.

In practicing the invention an aluminum alloy body having the above described composition is provided preferably by continuous direct chill casting techniques. The body is subjected to an elevated temperature exposure at a temperature of at least 800°F, and

preferably between 850° to 900°F, for at least 4 hours. This treatment, which is considered a homogenization, overcomes as-cast dendritic microsegregation and provides an essentially uniform microstructural distribution of the primary solute elements Zn, Mg and Cu. However it also causes some precipitation in situ of Cr as $Al_{12}Mg_2Cr$ particles, hereinafter E phase particles, which have a median size of 750 Å and a maximum size generally not exceeding 1000 Å. After homogenization the body is subjected to a carefully controlled high temperature treatment wherein it is heated to a temperature of at least 940°F and preferably between 950° and 1000°F. It is held at this temperature for a period generally of 6 to 48 hours. The heating rate to the high temperature preferably does not exceed 150°F per minute. This high temperature treatment agglomerates and dissolves precipitate particles of the $Al_{12}Mg_2Cr$, E phase, which precipitated from supersaturated solid solution during the initial elevated temperature exposure treatment. During the higher temperature treatment these particles grow to a median size of 1400 Å with some reaching up to 3000 Å. This type of temperature exposure is normally not employed on this type of alloy which is normally subjected to lower treatments not exceeding 870°F because eutectic melting occurs at 890°F.

After the elevated temperature exposure, the alloy body is typically hot rolled, preferably at a temperature of 650°F to 850°F to produce a slab which is then further rolled to produce a plate. The special elevated temperature exposure need not be applied at the ingot stage and can be applied after the alloy body is rolled to slab, plate, or the like, but the use of this treatment at the ingot stage is often the most practical. The hot rolled plate is then typically further rolled employing hot, warm or one or more continuous rolling operations which preferably end with a cold rolling step. It is significant that these final rolling operations impart to the sheet product an amount of strain hardening and grain fragmentation equivalent to that which would be developed in a cold rolling cross sectional reduction of at least 25% and preferably at least 45%. As just mentioned it is preferred that some if not all of the hardening effect be imparted directly by a cold rolling reduction as such in which case the hot, warm, or continuously rolled product may, if desired, be annealed by heating at 600° to 800°F prior to cold reduction especially where the latter is rather severe, for example over 35 percent cold reductions are especially useful in producing thin gauge sheet, for instance sheet under 0.150 inch thick.

The sheet product is subjected to a high temperature solution heat treatment at a temperature of 940°F to 1000°F, and preferably 960°F or higher. This treatment is important because it dissolves fine $Al_{12}Mg_2Cr$ particles, E phase particles, which precipitate during the thermo-mechanical treatments which followed the initial high temperature thermal treatment. It is noteworthy that solution heat treatment as contemplated by the improved method involves temperatures somewhat above those conventionally used which usually range from 860° to 920°F. For instance MIL Spec H-6088D, Amendment 2, prohibits temperatures over 930°F for solution treatment of 7075 sheet and over 880°F for 7075 alloy in other forms. The total time at temperature during the solution heat treatment should be at least one-quarter hour, and preferably 2 hours or

longer, although as described in more detail later, circumstances may arise where it is advisable to provide some of the solution heat treatment just prior to the cold reduction, in which case the duration of the solution heat treatment after cold rolling can be reduced to as low as about 3 minutes. After the solution heat treatment, the sheet is quenched, preferably by spray quenching or by immersion in water at a temperature not in excess of 100°F.

The quenched sheet is then artificially aged to fully develop its properties. The aging treatment may consist of 10 to 180 hours at a temperature of from 200 to 255°F to produce the alloy sheet in what may be called an isothermal T6 type temper in which the sheet exhibits the optimum combination of strength and resistance to tearing. While material in this temper may be preferred in some instances, it is worth noting that it is not as resistant to stress corrosion cracking as would be the case if the sheet were imparted with what might be called a step T6 type temper where it is heated in stages, the first stage being a 2 to 100 hour treatment at a temperature of 200° to 255°F and the second being a 2 to 12 hour treatment at a temperature of 300° to 335°F. This increased resistance to stress corrosion cracking is obtained with no sacrifice in strength and a small sacrifice in tear resistance relative to that attained using the isothermal T6 type temper. The sheet will develop yet another combination of properties if it is aged to what might be called a T7 type temper where it is also heated in stages and where the second stage is a 6 to 24 hour treatment at 315°F to 350°F. Sheet treated in this way develops slightly lower strength, higher resistance to stress corrosion cracking, and higher toughness relative to that of material treated by an isothermal or a step T6 type treatment. In either two step treatment (T6 type or T7 type) the time in the second step is generally inverse to the temperature to avoid excessive aging effects.

One embodiment of the invention contemplates the improved sheet as a core layer in a clad sheet wherein a protective outer layer serves to prevent corrosion of the core. The protective cladding is in an alloy more anodic than the core to provide the desired protection. These composites are well known in the aircraft industry for their usefulness although such would be greatly enhanced if the core would be imparted with improved toughness. The clad sheet is produced in a manner very similar to that described earlier for the bare sheet. In the primary ingot breakdown the cladding is hot rolled bonded to the previously thermally treated ingot and the fabrication proceeds as with the bare sheet. Suitable cladding alloys include the nominal compositions listed below in Table I.

TABLE I

A	Al, 1% Zn
B	Al, 2% Zn, 0.5% Mg
C	Al, 5% Zn, 1.25% Mg
D	Al, 5% Zn, 1.25% Mg, 0.75% Si

Some of the cladding compositions listed above are themselves considered as contributing to the strength of the clad composite. For instance, compositions B, C and D are heat treatable thus imparting to the clad product a higher composite strength. Although excessive diffusion is generally not observed in the improved clad sheet more diffusion of core elements to the cladding occurs than is usual in conventionally heat treated

clad 7075 type sheet. This increase is attributed to the 960°F solution heat treatment. To insure that the extent of any diffusion is not excessive, that is, that the solution potential of the cladding surface would not approach that of the core, care to avoid excessive exposure time is warranted. One approach is to expose the sheet prior to cold rolling to a 1-hour treatment at 960°F, cool to room temperature, cold roll and then final solution heat treat the sheet briefly, around 3 to 20 minutes, at 960°F after which it is quenched. The second exposure at 960°F may be in a continuous furnace. This approach offers the advantage of the prolonged exposure to solution temperature being performed while the cladding is much thicker, prior to the final cold reduction, so that the diffusion path to the cladding surface is longer.

As already suggested a property of great importance in the aircraft industry is resistance to stress corrosion cracking which, as described in U.S. Pat. No. 3,198,676, can be improved in Al-Zn-Mg-Cu type alloys by employing a two-step aging treatment. As indicated in that patent, good resistance to stress corrosion cracking correlates well with an accelerated test where stress is applied in a specimen amounting to 75 percent of the specimen's yield strength and exposing the specimen so stressed to alternate immersion in an aqueous solution containing 3.5 percent sodium chloride. In that patent the type of product of primary concern exhibited rather thick cross section such that the short transverse properties become significant. In stress corrosion testing the short transverse property is of most interest since it is the most sensitive. In the alternate immersion test, survival of the specimen for 84 days, approximately 3 months, correlates well with substantial immunity to stress corrosion cracking effects in normal environments. However, in a sheet product the short transverse properties are not readily utilized and are not measured or tested. Accordingly, stress corrosion test specimens are taken in the long transverse direction, the direction in the plane of the sheet but normal to the direction of rolling. Here a meaningful test requires 6 months to complete. Where the sheet is clad the test period has to be extended to one year in order for the results to be considered reliable for use in high performance applications such as aircraft. That is, while shorter duration tests such as a 3-month test are useful in sheet products on a preliminary basis, reliable testing requires much longer periods of 6 months for bare sheet and one year for clad sheet. Because sheet is often formed after it has been precipitation heat treated, the resistance to stress corrosion cracking of plastically deformed sheet must also be determined. The specimens used to evaluate the stress corrosion performance of sheet are referred to as "preform" specimens and are described in the Proceedings of the ASTM, Volume 65, 1965 on pages 182-197. Repeated tests of the type just outlined establish that the improved sheet, clad or unclad, possesses the same order of resistance to stress corrosion cracking as 7075 type alloys in the various tempers. That is, the described improvements are realized without any sacrifice in this important property.

In order to further illustrate the invention and the advantages derived therefrom, the following illustrative examples 1 through 3 proceed.

EXAMPLE 1

Three ingots containing 5.72-5.84% Zn, 2.42-2.49% Mg, 1.37-1.53% Cu, 0.19-0.20% Cr, 0.07-0.08% Fe, 0.07% Si, 0.02% Ti, 0.01-0.03% Mn, the balance being aluminum were prepared by continuous casting. The ingots were exposed for 6 hours at 860°F and then heated at not more than 150°F per hour up to a 980°F hold temperature and held for 24 hours. The ingots were air cooled to room temperature and thereafter clad with alloy A in Table I and hot rolled during which their temperature did not fall below 750°F to produce slabs about 4 inches in thickness. The slabs were then reheated to a temperature of about 860°F, and then hot rolled to provide plate approximately three-fourths inch in thickness. This plate was rolled on a continuous multi-stand mill to produce sheet which was about 0.18 inch in thickness. At this point the 0.18 inch sheet was annealed at a temperature of 775° F to soften it for cold rolling. The sheet was then cold rolled to produce sheet about 0.090 inch in thickness, a cold reduction of just about 50 percent. This sheet was solution heat treated for 1 hour at 960°F and quenched by spraying with water maintained at a temperature <100°F. At this point the material was stretched to flatten, then divided into three portions each of which was subjected to a different aging treatment to provide material: (1) in an isothermal T6 type temper (24 hours at 250°F), (2) in a step T6 type temper (3 hours at 245°F, plus 3 hours at 315°F) and (3) in a T7 type temper (3 hours at 250°F plus 12 hours at 325°F). The average transverse properties, which are those of prime importance in sheet products, for the sheets from the three ingots are shown in Table II along with like properties of comparison sheets of 7075 sheet with the same cladding and in the two step T6 temper. The comparison 7075 sheet was fabricated in the same manner as the improved sheet except for the omission of the high temperature thermal treatment after homogenization and the use of a solution heat treatment temperature of only 870°F. The aging treatment for the 7075 was the standard step T6, 3 hours at 245°F plus 3 hours at 315°F. Tear resistance was measured by the Kahn tear test as described in The Welding Journal published by the American Welding Society, Volume 27, page 169 (1968). In this test an autographic load-deformation curve is obtained while a crack is initiated in and propagated across a test specimen. The total area under the load-deformation curve is a measure of the energy required to initiate and propagate a crack, conveniently expressed as inch-pounds per square inch. That portion of the area following the maximum load application determines the energy required to propagate the crack, and when completed on a unit basis in inch-pounds per square inch is defined as unit propagation energy, abbreviated UPE. The tear strength is also determined, and the ratio of the tear strength to the tensile yield strength is also usually calculated because it gives a measure of the ability of the material to deform plastically in the presence of a stress raiser.

TABLE II

Transverse Properties for Clad Sheet

Material	T.S. ksi	Y.S. ksi	% El. in 2"	UPE in.-lb./in. ²	Tear Strength to Y. S. Ratio
A-Improved T6 iso.	77	66	14	810	1.44
B-Improved T6 step	76	67	12	690	1.41
C-Improved T7	74	65	11	825	1.44
D-7075-T6 step	78	67	11	225	0.97

From the table it becomes apparent that the improved clad sheet composite has tensile (T.S.), yield strength (Y.S.) and elongation levels readily comparable to those of clad 7075 alloy and others of this type. However, the UPE and tear strength to yield strength ratio (a measure of ability to deform plastically in the presence of a stress raiser) of the improved sheet are much higher than those of 7075 alloy. Also the toughness of the improved sheet is higher than for other alloys of the 7075 type, for instance, referring to U.S. Pat. No. 3,198,676, it can be seen that 0.064 inch sheet of other 7000 type alloys cannot be depended upon to exhibit transverse UPE levels much above 200. The improved sheet obviously represents a marked improvement.

EXAMPLE 2

In addition to tear test data (UPE) of the type presented in Example 1, another measure of toughness and tear resistance in sheet well known in the fracture mechanics field is that of the sheet's critical stress intensity factor K_{Ic} . In this approach to testing, large sheet samples typically 44 inches in length and 16 inches in width are tested to determine crack propagation effects. The long dimension corresponds to stress direction; where the transverse properties are being tested, the long dimension corresponds to the direction in the plane of the sheet that is perpendicular to the principal rolling direction. The sheet thickness is not critical in the test although it should be representative of the product contemplated. The sample, shown in FIG. 2, is prepared for testing by having a hole machined or drilled in its center. Slots are provided parallel to the short dimension of the sample. The sheet is gripped at each end and a tension load is applied along the length of the sample. This force is applied until a crack is just initiated at each end of the slot. Once the cracks are initiated the meaningful part of the test commences. A constantly increasing load is applied until the crack growth becomes unstable, that is, a crack propagates at an instantaneous or almost explosive rate. This would be symbolic of a catastrophic instantaneous tear failure which could possibly occur in aircraft skin with disastrous results. K_{Ic} is calculated from gross area stress (load divided by original cross section area, $16'' \times$ thickness), and from crack length at the onset of rapid crack propagation. Consequently, K_{Ic} is a measure of a material's ability to tolerate a crack under stress without failing catastrophically. The higher the K_{Ic} value, the greater the tolerance for the sheet material to sustain a crack of greater length without failing catastrophically. Once K_{Ic} is obtained, the residual strength of cracked panels can be calculated. This concept is described further in the Special ASTM Committee Report "Fracture Testing of High Strength Sheet Materi-

als", ASTM Bulletin No. 243, January 1960, pages 29-40. A comparison of the improved sheet in both of the two-step aging tempers with 2024-T3 and 7075-T6 sheet is shown in the curves of FIG. 3 where curve I-1 represents the improved material in the two-step T7 type temper and curve I-2 applies to the two-step T6 type temper. In viewing FIG. 3, it can be seen that the improved material is somewhat superior to alloy 2024-T3 which is considered to be a high tear resistant material although its lower tensile and yield strengths require use of thicker sections and consequently necessitates an appreciable weight penalty in aircraft and other weight-critical applications. Alloy 7075 is clearly inferior in tear resistance to both 2024 and the even more favorable improved alloy sheet, curves I-1 and I-2. In viewing FIG. 3 it can be seen that for each sheet the length of the crack can be increased without affecting the gross area stress at failure GS up to some point after which lengthening the crack drastically reduces GS. Comparing the improved sheet versus 7075 alloy sheet, it can be seen at a GS of 30 ksi 7075 sheet will fail if the crack reaches about $2 \frac{1}{2}$ inches in length whereas the improved sheet will sustain crack lengths of over 5 and over 6 inches depending on the aging treatment, that is, the crack length can be twice or even three times the crack length where the 7075 sheet failed. Another comparison might be to consider a 6 inch crack and FIG. 3 indicates that 7075 alloy sheet fails at less than 20 ksi GS whereas the improved sheet approaches and exceeds 30 ksi GS. This type of test is perhaps the most important to the aircraft industry since such determines the actual extent to which a material can sustain cracks. A material which appears favorable in this test inherently provides for greater safety and greater periods between inspection of an aircraft's skin for cracks.

In addition to the data shown in FIG. 3, the comparison set forth in Example 1 and Table II is presented in the terms of K_{Ic} in Table III below. In the table the sheet material designations refer to Table II as does the UPE data.

TABLE III

Transverse Tear Data

Sheet Material	UPE	K_{Ic}
A	810	118
B	690	105
C	825	120
D	225	63

From the foregoing table and FIG. 3, it is quite apparent that the improved material, curves I-1 and I-2 in FIG. 3 and materials A, B and C in Table III, represents a marked improvement in toughness and tear resistance over alloy 7075 sheet.

EXAMPLE 3

In addition to the very important aspect of catastrophic or unstable cracking, the area of stable crack propagation in fatigue is also of great importance in sheet applications. In fatigue testing a sample of the general configuration described in Example 2 but about $4 \times 14 \frac{3}{4}$ inches in size is prepared and a crack initiated along the lines of Example 2. However, the applied load in this case is rather low but is of a cyclic nature. The meaningful part of the test commences after cracks initiate from both ends of the hole and propa-

gate to a total length, including the starter hole, of 0.50 inch. To determine the rate of fatigue crack propagation, cyclic axial tension loads of varying levels are applied to specimens and the rate of crack growth in terms of microinches per cycle is measured. The stress intensity factor K, as described above, is proportioned to the stress at the tip of a propagating crack. The longer the crack becomes, the greater becomes the stress intensity factor K for a given gross area stress GS. Table IV below lists a comparison between the improved sheet and 7075 sheet both clad with alloy A from Table I and 0.090 inch in thickness at varying levels of the stress intensity factor K.

TABLE IV
Crack Growth Per Cycle

K (ksi $\sqrt{\text{in.}}$)	Improved	7075
10	6	7
20	35	50
30	90	300
40	260	1000

It can be seen in the table that at the relatively low levels of K, for instance 10 or 20 ksi $\sqrt{\text{in.}}$, the performance of the improved sheet is not strikingly different from that of 7075 sheet. However, at the higher and more critical K levels, for example K=30 or 40, the fatigue crack propagation rate in 7075 sheet becomes approximately four times that of the improved sheet. This again verifies that the improved sheet provides greater safety and extends the periods required between inspections for cracks in aircraft skin and similar critical applications.

From the foregoing and the further illustrative examples which follow it can be seen that the improved sheet product exhibits a unique combination of strength and toughness or resistance to tearing. The improved sheet has consistently demonstrated a typical K_{IC} of 85 ksi $\sqrt{27\text{in.}}$ or more at yield strength levels up to 70 ksi and even higher in the transverse direction which is the critical direction in sheet type products. This property is conspicuously peculiar to the improved sheet. For instance, while 2024 alloy sheet also exceeds 7075 sheet in tear resistance, its use is limited by its lower strength. The yield strength for the improved sheet is substantially the same as that associated with 7075 sheet products and generally ranges from 60 to 75 ksi depending largely on the aging treatment. The minimum critical stress intensity K_{IC} ranges, generally inversely with yield strength, from about 75 to about 85 or even 100 and higher ksi $\sqrt{\text{in.}}$. Nonetheless, a yield strength of 70 ksi and a K_{IC} level of 85 ksi $\sqrt{\text{in.}}$ or more certainly typifies the improved material which can be contrasted with 7075 sheet material having a yield strength of 70 ksi but a typical K_{IC} of only 60. The markedly improved properties of the improved sheet appear to be associated with certain features which are revealed on examination. The improved sheet exhibits: (1) a pattern of fine grains, from 300 to 10,000 or more grains per cubic millimeter, (2) an E phase $\text{Al}_{12}\text{Mg}_2\text{Cr}$ precipitate, particle size median of at least 1400 angstroms and (3) a low volume fraction of iron-bearing phase, less than 0.45%, and of silicon-bearing phase, less than 0.25%. These characteristics can be contrasted with conventional 7075 sheet which may or may not have fine grains and wherein the E phase particle size rarely exceeds 1,000 Å with the median size being about 750 Å.

The volume fraction in 7075 sheet for iron-bearing phase is up to 2.4% and typically about 1.4%, and for the silicon-bearing phase up to 1.7% and typically about 1%. The above described characteristics of the improved sheet appear to result in the markedly and surprisingly improved properties in that conventional 7075 sheet, without these characteristics, exhibits comparatively low tear resistance.

To illustrate the importance of the limits described in connection with the invention, the following further examples proceed.

EXAMPLE 4

Clad sheet, 0.090 inch thick, was fabricated in a sequence substantially identical with that of Example 1. The core contained 5.8% Zn, 2.6% Mg, 1.8% Cu, 0.19% Cr, balance essentially aluminum and 0.07% Fe and 0.04% Si as impurities. The cladding contained 5.3% Zn, 1.1% Mg, 0.03% Cu, 0.21% Cr, balance aluminum and impurities. The fabrication sequence included the high temperature thermal treatments, including solution heat treatment, in accordance with the invention and the sheet was aged for three hours at 245°F plus three hours at 315°F, a two-step T6 type treatment. The long transverse properties of the composite and of specimens from the core are shown below in Table V.

TABLE V

	T.S. ksi	Y.S. ksi	% El. in 2"	UPE in.-lb/in. ²	Tear Str. Y.S.
Composite	81	74	12	220	0.86
Core	86	79	12	120	0.85

From the foregoing table it becomes immediately clear that the UPE of this sheet is drastically reduced in comparison with the improved clad sheet described in Example 1. This together with several other tests have verified that increasing the magnesium content from the herein described maximum of 2.5% up to a mere 2.6% results in a marked deterioration of tear resistance. That is, controlling Mg within the herein prescribed limits of 1.9 to 2.5% surprisingly enables achieving both high strength and very high toughness.

EXAMPLE 5

Sheet containing 5.8% Zn, 2.3% Mg, 1.6% Cu, 0.20% Cr, balance aluminum and 0.01% Fe and 0.01% Si as impurities was produced without cladding but otherwise substantially as described in Example 1 except that some of the sheet included a 50% cold rolling reduction and some included no cold rolling reduction. All the sheet was aged 24 hours at 250°F, an isothermal T6 type treatment. The long transverse properties of both sheets are shown below in Table VI.

TABLE VI

% Cold Roll	T.S. ksi	Y.S. ksi	% El. in 2"	UPE in.-lb/in. ²	Tear Str. to Y.S. Ratio
0	80	73	15	395	1.35
50%	80	71	15	1005	1.44

From Table VI it becomes clear that material in accordance with the improved composition which has received the improved thermal treatments is sensitive to cold rolling which can be employed to optimize tear resistance in that the sheet which received a 50% cold reduction exhibits greatly improved tear resistance over that which received no cold reduction.

EXAMPLE 6

Sheet containing 5.5% Zn, 2.5% Mg, 1.65% Cu, 0.25% Cr, balance essentially aluminum and 0.07% Fe and 0.08% Si as impurities was produced by hot rolling followed by cold rolling to the final gauge of 0.064 inch. The cold rolling reduction amounted to over 50% but the ingot included only a 16 hour homogenization treatment at 860°F and no high temperature treatment in accordance with the invention. The sheet was solution heat treated at a temperature of only 860°F. These thermal treatments are in accordance with current practices for 7075 type alloy sheet. The unit propagation energy for this sheet was only 340 in.-lb/in.².

In comparing Examples 5 and 6 it becomes clear that to dependably achieve high tear resistance of over 400 UPE the improved thermal treatments should be employed along with substantial strain hardening effects. In Example 6 where the sheet composition was in accordance with the invention but there was no thermal treatment in accordance with the improved method, a cold reduction of over 50% failed to bring the tear resistance up to the desired level. In Example 5 it can be seen that a 50% cold reduction markedly improves tear resistance on sheet otherwise in accordance with the invention.

EXAMPLE 7

To illustrate further the influence of cold rolling on the improved sheet and that the improvement derived therefrom is progressive, an ingot containing 5.7% Zn, 2.4% Mg, 1.3% Cu, 0.2% Cr, balance aluminum and impurities in accordance with the invention was fabricated into 0.180 inch thick sheet generally according to the practice described in Example 1. The sheet was annealed and divided into several portions which were cold rolled to various reductions after which they were solution heat treated one hour at 960°F, quenched and then aged 24 hours at 250°F, an isothermal T6 type treatment. The yield strength of all the sheet was approximately 72 ksi and the unit propagation energy levels for the various sheet portions are listed below in Table VII.

TABLE VII

Percent Cold Rolling	UPE in.-lb/in. ²
0	430
25	555
30	590
35	640
40	625
45	690
50	805

From table VII it can be seen that cold rolling prior to solution heat treatment has a significant influence on the tear resistance developed in the improved sheet. By way of comparison sheet having the same composition as that described in Example 5 was fabricated in accordance with the invention, including a 50% cold rolling

reduction, except that the solution heat treatment temperature was reduced to only 915°F. The UPE for this sheet was only 285 in.-lb/in.² which again underscores the cooperation of the thermal treatment with the other factors described herein for the improved method.

The method described above including two separate high temperature thermal treatments is preferred since it dependably results in the desired improved sheet product. This is especially so where the initial metal form is an ingot or other body or slab of substantial thickness, over eight inches, which is reduced to produce the sheet product. In this case we have found it highly preferable that both high temperature thermal treatments be employed, that is, at the ingot or other thick slab stage and at the solution heat treatment stage. However, especially where the starting material is a relatively thin body, for example, a cast plate 1 or 2 inches thick, or where exposure of rather extended duration can be tolerated in solution treatment, a substantial amount of the benefits of the invention can be achieved by a single exposure to a metal temperature of at least 940°F. Accordingly, in its broadest aspect, the invention contemplates a single high temperature treatment although on a somewhat less preferred basis. That is, in its broadest aspect the invention contemplates sufficient exposure to temperature over 940°F, and preferably between 950° and 1000°F, to provide the desired 1400A or larger E phase median particle size.

While this description emphasizes sheet and its production, it is to be understood that such refers to a rolled product which can range in thickness up to about 0.25 inch and even more. It is not intended that the term "sheet" necessarily refer to arbitrary numerical restrictions often employed to separate sheet from plate, and the like, type products. Nonetheless a preferred embodiment of the invention contemplates sheet ranging in thickness from about 0.020 inch to about 0.250 inch since such is most useful in the aircraft industry where the highest possible strength and tear resistance is needed for skin covering.

What is claimed is:

1. A method of producing an aluminum base alloy sheet or plate product having high strength and high toughness and resistance to crack propagation comprising:
 1. providing a body of aluminum base alloy consisting essentially of 5.2 to 6.2% Zn, 1.9 to 2.5% Mg, 1.2 to 1.9% Cu, 0.18 to 0.25% Cr, the balance being aluminum and not more than the following amounts of impurities: 0.12% Fe, 0.10% Si, 0.06% Mn, and 0.06% Ti,
 2. homogenizing said body at an elevated temperature not exceeding its eutectic temperature of about 890°F for a sufficient period of time to provide a homogeneous distribution of the readily soluble alloy elements,
 3. further heating said body at a rate not exceeding 150°F per hour to a temperature of at least 940°F for a period of at least 6 hours,
 4. hot rolling said body to reduce its thickness and thereafter further rolling said body to produce said product, said rolling operations imparting to said product strain hardening effects equivalent to a cold rolling reduction of at least 25% in thickness.

said product, when solution heat treated, quenched and artificially aged, exhibiting improved toughness together with high strength.

2. The method according to claim 1 wherein said product is artificially aged at a temperature of from 200° to 255°F for 10 to 180 hours.

3. The method according to claim 1 wherein said product is artificially aged by heating to a temperature of 200° to 255°F for 2 to 100 hours and thereafter heating to 300° to 335°F for 2 to 12 hours.

4. The method according to claim 1 wherein said product is artificially aged by heating to a temperature of 200° to 255°F for 2 to 100 hours and thereafter heating to 315° to 350°F for 6 to 24 hours.

5. The method according to claim 1 wherein, referring to said step (4), the said product is imparted with the equivalent of a cold reduction of at least 45%.

6. The method according to claim 1 wherein, referring to said step (4), the body is cold rolled to a cold reduction of at least 25% in thickness to produce said product.

7. The method according to claim 1 wherein, referring to said step (3), the body, after homogenization, is heated to a temperature between 950° and 1000°F.

8. The method according to claim 1 wherein the product is solution heat treated at a temperature of at least 940°F.

9. The method according to claim 1 wherein the product is solution heat treated at a temperature of from 950° to 1000°F.

10. The method according to claim 6 wherein said product ranges in thickness from 0.020 to 0.250 inches.

11. The method according to claim 1 wherein the further heating of said step 3 is performed subsequent to a hot rolling operation.

12. A method of producing an aluminum base alloy sheet or plate product having high strength and high toughness and resistance to crack propagation comprising:

1. providing a body of aluminum base alloy consisting essentially of 5.2 to 6.2% Zn, 1.9 to 2.5% Mg, 1.2 to 1.9% Cu, 0.18 to 0.25% Cr, the balance being aluminum and not more than the following amounts of impurities: 0.12% Fe, 0.10% Si, 0.06% Mn, and 0.06% Ti,

2. producing said sheet or plate product from said body including: (a) rolling operations which impart to said product strain hardening effects equivalent to a cold rolling reduction of at least 25% in thickness and (b) a thermal exposure to a temperature of at least 940°F sufficient to provide in said product E phase particles having a median size of at least 1400 Å.

13. An improved aluminum base alloy sheet or plate product composed of an alloy consisting essentially of 5.2 to 6.2% Zn, 1.9 to 2.5% Mg, 1.2 to 1.9% Cu, 0.18 to 0.25% Cr, the balance being aluminum and not more than the following amounts of impurities: 0.12% Fe, 0.10% Si, 0.06% Mn and 0.06% Ti, said product having a fine grain structure, a median particle size of 1400 Å or larger for the E phase precipitate and low volume fractions of less than 0.45% iron-bearing phase and less than 0.25% silicon-bearing phase, said product, when

solution heat treated, quenched and artificially aged, exhibiting a minimum K_{IC} of 100 to 75 ksi $\sqrt{\text{in.}}$ at yield strength levels of 60 to 75 ksi.

14. The improved product according to claim 13 which is clad on at least one side thereof with a layer of an aluminum base alloy which is anodic thereto.

15. An improved aluminum base alloy sheet or plate product composed of an alloy consisting essentially of 5.2 to 6.2% Zn, 1.9 to 2.5% Mg, 1.2 to 1.9% Cu, 0.18 to 0.25% Cr, the balance being aluminum and not more than the following amounts of impurities: 0.12% Fe, 0.10% Si, 0.06% Mn and 0.06% Ti, said product having a median particle size of 1400 Å or larger for the E phase precipitate and low volume fractions of less than 0.45% iron-bearing phase and less than 0.25% silicon-bearing phase, said product, when solution heat treated, quenched and artificially aged, exhibiting high toughness at high yield strength levels.

16. A method of producing an aluminum base alloy sheet or plate product having high strength and high toughness and resistance to crack propagation comprising:

1. providing a body of aluminum base alloy consisting essentially of 5.2 to 6.2% Zn, 1.9 to 2.5% Mg, 1.2 to 1.9% Cu, 0.18 to 0.25% Cr, the balance being aluminum and not more than the following amounts of impurities: 0.12% Fe, 0.10% Si, 0.06% Mn, and 0.06% Ti,

2. producing said sheet or plate product from said body and including a thermal exposure to a temperature of at least 940°F sufficient to provide in said product E phase particles having a median size of at least 1400 Å.

17. In a method of producing an aluminum base alloy rolled sheet or plate product having high strength and high toughness and resistance to crack propagation the improvement comprising:

1. providing a body of aluminum base alloy consisting essentially of 5.2 to 6.2% Zn, 1.9 to 2.5% Mg, 1.2 to 1.9% Cu, 0.18 to 0.25% Cr, the balance being aluminum and not more than the following amounts of impurities: 0.12% Fe, 0.10% Si, 0.06% Mn, and 0.06% Ti,

2. homogenizing said body at an elevated temperature not exceeding its eutectic temperature of about 890°F for a sufficient period of time to provide a homogeneous distribution of the readily soluble alloy elements,

3. heating said body to a temperature of at least 940°F for a period of at least 6 hours,

said product, when solution heat treated, quenched and artificially aged, exhibiting improved toughness together with high strength.

18. The method according to claim 17 wherein in said step (3) said further heating to at least 940°F is at a rate not exceeding 150°F per hour.

19. The method according to claim 17 wherein rolling procedures are employed which impart to the rolling stock strain hardening effects equivalent to a cold reduction of at least 25%.

20. The method according to claim 17 wherein the further heating of said step (3) is performed subsequent to a hot rolling operation.

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