Role of Indian ordnance factories in the development and manufacture of some of the important cast and wrought aluminium alloys during the last three decades

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SYNOPSIS

Manufacture of aluminium alloy castings to BSS 3L5, Y-alloy to 2L-24, modified aluminium-silicon alloy to L-33 and a few other such aluminium alloys was established in the Indian Ordnance Factories, Metal and Steel Factory, Ishapore, in the early thirties for their use in the production of different types of service components. Cold rolling of pure aluminium as well as of low aluminium alloys was a regular production item in early twenties in the 2-High, 24", 18", 16" and 12", D.C. electric motor driven cold rolling mills, which were installed in the Ordnance Factories in 1895 and are still in operation at Metal and Steel Factory, Ishapore. Probably this is the first cold rolling mill of its type, installed and put into operation in India. Satisfactory extrusion of brass rods by the inverted process, as developed by the Research Department of Woolwich Arsenal, U.K., led to the design and manufacture of an extrusion press of 900 tons power at 1-½ tons per square inch hydraulic water pressure by Messrs Henry Berry and Co., of Leeds, which after a few experimental runs, was acquired by the Indian Ordnance Factories and installed at Metal and Steel Factory, Ishapore, in 1924 for extrusion of brass and other non-ferrous alloy rods up to 2-¼" diameter from billets of 6-5/8" dia. × 24" long. This is the first extrusion press which has been installed in India for the commercial production of extruded non-ferrous metals and alloys, primarily from copper-base alloys and a small percentage from aluminium and its alloys. This 900-ton extrusion press was used for small scale production of untreated duralumin bars (Specification 17S) in late thirties and untreated super-duralumin bars in the beginning of world war II at Metal and Steel Factory, Ishapore, by adopting melting, extrusion and treatment technology, as developed by Metal and Steel Factory, themselves. The press is still in regular production at Metal and Steel Factory, Ishapore.

NON-FERROUS alloys are generally those, wherein metals other than iron, form the main or principal constituents. But it is not always the fact that non-ferrous alloys should be absolutely free from iron. There are many cases, where iron is purposely added, to develop certain beneficial properties while in some, the presence of this element is carefully eliminated to produce some sort of non-magnetic property.

The word 'alloy' is derived from the Latin word 'alligo' (ad-ligo) 'to bind to' and refers to the union of metals constituting an alloy. In English language, this word 'alloy' as ordinarily used, like 'un-alloyed love, un-alloyed happiness', conveys a meaning signifying a depreciation or lowering of value ; metallurgists however interpret the meaning of the term in a totally different way. To them, alloying of metals means, production of new combinations or compounds with new sets of properties, superior to those of the constituent elements. Copper, for example, has got certain basic properties or unusual significance in the development of industrial economy. The valuable properties like high electrical and thermal conductivity, good strength, malleability, resistance to corrosion, etc., which copper generally possesses, can be improved further by alloying it with certain other metals in certain proportions. Metallurgical world will reveal that such instances are not rare. Besides control of alloying elements, the method of fabrication forms another important factor in bringing in further developments in the physical properties of the alloys.

It is known from the periodic table, that there are only 92 elements, in this world, each with a separate and distinct property of its own. Excepting these 92 elements, all other things that we see around us, are

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nothing but combinations of these elements in some form or other.

Manufacture of various non-ferrous alloys with new combinations is increasing day by day in this scientific world and still the energy of the metallurgists to explore alloys with more valuable properties goes unabated. They have searched in the past, are searching now and most probably will go on searching in future, for the years to come, to invent more new alloys, with new sets of properties, which could more profitably be utilised in different trades and industries for the general benefit and uplift of mankind and to ensure speedy march towards technical advancement.

Earlier work

In the beginning of the 20th century, metallurgists first thought of alloying aluminium with different metals for developing different properties. Echevarri (J.I.M. 1909, vol. I, Page 125) mentioned that the studies of aluminium were confined, at that time mostly, to manufacture of pure aluminium in the form of (i) castings, (ii) rolled bars and sheets, (iii) drawn sections and (iv) hard and soft drawn wires. Applicability was also confined to few restricted cases e.g., deoxidation of steel, manufacture of castings and also in powder form as paint. Metallurgists of that period had a strong belief that alloys of aluminium with copper and a third metal, would have a wide field of applicability in the near future. The first alloy of aluminium which was manufactured by Carpenter and Edwards (J.I.M. 1909, vol. II, pages 125–130), was not very successful and had additives of 20% Zn, 6% Cu and 5% Ni. Successful manufacture of aluminium alloys was achieved after the above experiment. Alloys of Al with Zn were first studied by Roseneain and Archball (J.I.M. 1911 No. 2, vol. VI, page 236) as well as by Heycock and Nevile (J.I.S. vol. IXXI 1897, page 389).

Important aluminium alloys which are used at present industrially are :

(i) Alloys of aluminium with Cu, better known as aluminium-bronze.
(ii) Alloys of Al with Si or Zn and Cu as casting alloys.
(iii) Light wrought aluminium alloys of duralumin type.

Aluminium-bronze

Manufacture of both wrought and cast aluminium bronze was established in the Indian Ordnance Factories —Metal & Steel Factory, Ishapore, in the early thirties. Aluminium-bronze castings conforming to BS—1400 —ABI—C having chemical composition aluminium %8·5—10·5, iron % 1·5—3·5, manganese % 1·0 (max), nickel % 1·0 (max), zinc % 0·50 (max), total of other elements % 0·30 (max), copper % remainder, mechanical properties, ultimate stress ton/sq. inch (min), sandcast separately 32; cast on 32, elongation % (min). Sandcast separately 20·0, cast on 20·0, is a regular item of manufacture for the production of acid resisting parts. Earlier difficulties in the fabrication of wrought aluminium bronze greatly retarded the extensive application of this alloy, except in the form of cast products where design factors admitted use of such a product.

Later on, wrought aluminium bronze forged bars both of 10% aluminium bronze and aluminium-nickel-iron-bronze types conforming to ASTM B-28 (w) and DTD 197 having the composition aluminium % 9·5–10·5, iron % 1·0 (max), nickel % 0·20 (max), total of other elements % 0·50 (max), copper 8·95–90·5. Mechanical properties in quenched and tempered condition, ultimate stress ton/sq. inch 38·0–40·0, elongation% 12·0–22·0 and aluminium % 8·0–12·0, iron % 4·0–6·0, nickel % 4·0–6.0, nickel % 4·0–6·0, total of other elements % 0·3·0 (max) copper % remainder mechanical properties in quenched and tempered and condition 0·1%, proof stress tons/sq. inch 25·0 (min) and elongation %15·0 (min) were produced for fabrication of such parts as valve stems, propeller-blade bolts, air-pumps, condenser bolts as well as for different bushings and slide liners, needing high strength combined with good wear-resisting properties.

Cast alloy is melted in crucible in coke-pot holes and cast ingots for forging are melted in Morgars Oil-fired Tilting Furnace. Copper is melted first under reducing condition, followed by addition of aluminium as 50 : 50 copper-aluminium pig, iron as ferro-copper having 50% iron content and nickel as 80/20 copper-nickel alloy, melt is thoroughly mixed with a graphite rod, skimmed and poured gently in proper stream at an average tapping temperature of 1175°–1200°C. But the forging temperature range has been found to be between 760° and 900°C.

Heat-treatment is carried out by water quenching from temperatures 800°/850°C followed by tempering at 350° -600°C, according to the thickness of the section and composition of the alloy.

Aluminium-silicon, aluminium-zinc-copper alloys, 'Y'—alloy

Development in the founding of light alloys actually started since early thirties to meet the increased demands of the aircraft industry for such alloys where lightness and strength are of paramount importance. Besides aircraft, application of such light alloys has also greatly increased in many other general engineering work particularly for reducing inertia losses.

Manufacture of aluminium-copper-zinc alloy to BSS 3L5 having composition zinc % 12·5–14·5, copper % 2·5–3·0, impurities%(max. 1·50), aluminium remainder and mechanical properties—sand cast 0·1%, proof stress ton/sq. inch (min) 3·5, UTS ton/sq. inch (min) 9·0, elongation % (min) 2·6, chill cast 0·1%, proof stress ton/sq. inch (min) 3·5, UTS ton/sq. inch (min) 11·0, elongation % (min) 3·0 was established at Metal and Steel Factory, Ishapore, in mid thirties for the production of covers and other highly stressed service store parts. This alloy is alo used in automobile industry and other construction work. Adoption of this alloy in general engineering work ensures a good outlet for secondary metals.

Aluminium silicon alloy to BSS L-33 (modified) is regularly produced in the Indian Ordnance Factories both as sand cast and pressure die-cast component for the manufacture of different service stores where lightness and corrosion-resistance coupled with better mechanical properties are needed. This alloy is also used under different names, 'Alpax', 'Wilmil', 'Silmil' incorporating different properietory processing including modification treatment.

'Y' alloy conforming to BSS L-35 was also regularly manufactured in the Ordnance Factories for use in many service store parts.

Light wrought aluminium alloy duralumin type

Hanson and Gaylor (J. I. M. No. 2, 1921, Vol. XXVI, Page 349) first studied the action of Si and Mg, on aluminium. Gaylor later on (J. I. M. 1922, No. 2, page 236, vol, XXVIII) studied alloys of aluminium with Cu, Mg, and Si. She said that of the two essential constituents of such aluminium alloys namely, $CuAl_2$ and Mg_2Si, the latter actually plays an important part in developing age-hardening properties. Hanson and Gaylor (J. I. M. No 1, 1923, XXIX, page 497) further studied the action of small percentages of Cu on Al, and observed that copper-aluminium alloys containing 0·2% Cu, were not susceptible to heat-treatment while alloys containing 2·5 to 5·0% Cu readily respond to heat-treatment. Mary Gaylor (J.I.M. No. 2, 1923, vol. XXXI, page 161) observed again that age-hardening of alloys containing Al, Cu, Mg and Si, is primarily due to Mg_2Si and takes place in two stages—both at room temperature by the coalescence of the finely divided particles of Mg_2Si. Gaylor and Preston (J. I. M. 1929 (1) page 191) heat-treated five different aluminium alloys each having a different composition. The average composition varied as Cu, 2·0-4·5%, Si ·25-·50%, Mg, ·42-·85%.

One of these alloys having the composition Mg ·51% Si, ·30% Cu 4·0% Al-Diff was heat-treated as annealed at 500°C, then quenched at 500°C in water and aged at room temperature, followed by further ageing at higher temperature. Hardness developed B. H. 120–130, with 28 tonnes per sq. inch breaking stress and 10% elongation.

Meissner (Z. Metallkunde 1929, 21, 328–332) investigated the addition of, ·30%, Fe, ·30% Si and 60% Mn, alone, as well as together, on the increase in tensile strenght of an alloy having the composition 4·3% Cu, ·50% Mg, and 95·2% Al. He observed that Mg alone imparts age-hardening properties and that the addition of Fe, Si or Mn, individually has no effect, while their simultaneous presence as ·60% Mn, ·30% Si, and ·30% Fe, produce increased strength.

Meissner (J. I. M. 1930, No. 3, vol. XIV, page 207) studied a super-duralumin alloy having the following composition. Cu–4·40%, Mg–5·3%, Si–0·79%, Mn–0·61%, Fe-0·25% Al-Diff. With respect to the effect of artificial ageing upon the resistance to corrosion by sea-water, he gave the following heat-treatment, annealed at 500°C, then quenched in cold water from 500°C and aged at temperatures from 50–200°C for 20 to 40 hrs., and obtained the following physical properties, Y-30 kg/sq. mm, B-47 kg/sq. mm, E-12% (18/tons sq.in., B 28·2/tons/sq.in., E-12%).

Meissner observed that super-duralumin aged at temperature above 100°C, when compared with that aged at room temperature, shows a greater decrease in the P. C. of elongation in the former than in the latter case. This decrease shows that artificial ageing causes a more pronounced precipitation of the alloying components.

Sidery, Lewis and Sutton (J. I. M. 1932, vol. XLVIII, page 147) observed (i) higher the quenching temperature, the lower is the tendency to develop inter-crystalline corrosion, (ii) quenching in boiling water shows more propensity towards inter-crystalline corrosion than in cold water or oil.

Barchers and Schwarzamair (Z. Metallkunde, 1934, 35–237–241) studied the effect of various heat-treatment on a fully age-hardening Al-alloy having the composition ·77% Mg, ·82% Si, ·32% Fe, ·67% Mn, ·12% Ti., Diff Al. They obtained best hardness figures by annealing treatment at 320° and solution treatment of 1/2 hr. at 520°–540°C followed by ageing at 120° for 920 hrs. hardness then being 112 kg/sq. mm while the original hardness was 80 kg/mm. Treatment at too high a temperature produced anomalous results, an initial hardening followed by softening.

Marie Gaylor (J. I. M. 1937, No. 1, vol. LX) studied the effect of the addition of 60% Fe and 1·0% Si, to a high purity 4% Cu-Al alloy and found that the age-hardening which takes place at higher temperature, may be attributed to precipitation of Si as well as some $CuAl_2$ from the solution and that the presence of 60% iron inhibits age-hardening at higher temperature and 1·0% Si does not inhibit the effect of 60% Fe.

Petrov (J. I. M. 1938, No. 1, vol. LXIII, page 63) studied the influence of Fe and Mg on the age-hardening of copper-aluminium alloys. He observed the following :

(i) Room temperature age-hardening of Cu-Al alloys is completely eliminated with 2% Fe and 4% Cu due to formation of some insoluble compound having the composition Al, Cu_2 Fe, but the above lost capacity is restored by addition of a small p.c. of Mg.

(ii) The effect of small amount of Fe and Mg on the age-hardening of Cu-Al alloy is related to their influence on the lattice structure of the solid solution of Cu in Al.

Hideo Nishimura (Nippon Kinzcku Gakki-Si, Transaction Institute of Metals, Japan) 1939, 3 (ii) (420–424) studied effect of Fe, on the age-hardening of 24-9 type super-duralumin having the composition Cu%–4·45, Si%–·80, Mg% ·08, Fe%, ·40 and Mn% ·67 and like other observers, Gaylor and Preston, found that the presence of iron suppresses the age-hardening effect due to a decrease in the solid solubility of Cu in Al and Gungi Shinoda (Trans. Soc. Mech. Eng., Japan 1939 5 (21) (139-141) observed that internal strain and lattice distortion is not the cause of age-hardening.

Arrowsmith and Wolfe (J. I. M. May 1940, page 149) experimented on the use of refrigerator for delaying the age-hardening properties of duralumin type alloys and found that by storing in a refrigerator at temp. 6°C to 10°C, normalised sheets may be kept for 4 days without any age-hardening taking place.

Hanson and Dreyer (Aluminium 1940, 22 (3) (134-137) while studying the effect of Si, in amounts varying from 0 to 1·2% on the age-hardening of an alloy of Al with Cu, Mg, Mn at room temperature and at 160°C observed that (i) hardness and tensile strength are little affected by silicon during ageing at room temperature, (ii) Mg, plays an important part, (iii) at 160°C increase in Si accelerates ageing and increases the hardness, (iv) cold working tends to off-set the effect Si.

Igavashi and Kitahara (J. Soc. Aeronaut-Sci, Nippon 1939 (53) 982-996) studied the properties of some extra super-duralumin better known as F. S. D. with the following composition and properties :

Chemical composition

Cu%	Cr%	Zn%	Mn%	Mg%	Al%
2·0	·30	8·0	1·5	·50	Diff.

Yield (·20% proof stress)		50 kg (sq. mm)
U.T.S.	—	58 ,, ,,
Elong.	—	12% ,,

Extruded bar

Yield (·20% proof stress)		60 kg (sq. mm)
U.T.S.	—	68 kg ,,
Elong.	—	10%

Takuity Mutuzaki (Trans. Metals, Japan) 1941, 5(4) (121-123) later studied the effect of iron on the properties of super-duralumin but did not come to any definite conclusion.

Hyosi Nakata (Res. Rep. Sumitome Met. Industry E/W 1941-329-334) studied the effect of iron on the mechanical properties of super-duralumin and found that the decline in tensile properties with increasing iron content is gradual at first but beyond ·60% becomes rapid.

Dreyer and Seeman (Metallwris/chaff 1941, 20 625-629) studied the effect of Fe on age-hardening of duralumin type alloys in proportion of ·30%-1·30% with solution treatment at temperature ranging from 480°-540°C, quenched in water and tested after ageing at room temperature for periods up to 12 days. They observed that the mechanical properties decrease with iron content in excess of ·50%. Rate of age-hardening decreases with increasing iron content.

D. P. Chatterjee (Q. J. G. M. M. vol. XVII, No. 2, pages 52-57, 59-62, 1945 and vol. XVIII, No. 2, pages 42-52, 1946) studied melting, extrusion by inverted process, hot and cold rolling, stamping and treatment of two types of super-duralumin alloys as described below at Metal and Steel Factory, Ishapore, in early 1944 from Indian raw materials.

Chemical composition of the two alloys

Composition	High silicon Type 'A'	High silicon Type 'B'
Copper	4·62%	4·60%
Iron	0·62%	0·60%
Manganese	0·60%	0·58%
Magnesium	0·50%	0·45%
Silicon	1·24%	0·80%
Zinc	Trace%	Trace%
Sodium	Min. trace%	Min. trace%
Aluminium	Balance	Balance

Chatterjee found that 2¼" dia. bar extruded by the inverted process from 6¼" dia. cast and surface turned billet in the 900-ton horizontal Henry Berry extrusion press and conforming to the chemical composition of high-silicon type 'A' as detailed above, when water-quenched at 510°±2°C and age-hardened at room temperature for 168 hours, developed the following physical properties (0·10% Proof Stress 24·0-25·0 ton/sq. inch, U. T. S. 26·5-28·5 ton/sq. inch, Elongation 10·5-12·0% B. H. No. 105-110). He also observed that when the same material was water-quenched at 510°±2°C and accelerated age-hardened at 196 ± 2°C for 24 hours in an h.f. oil bath, it developed physical properties 0·10% Proof Stress 24·0 -24·5 ton/sq. inch, U. T. S. 28·0-30·0 ton/sq. inch, Elongation 8·0-8·5% BH No. 125-128.

High-silicon type 'B' alloy was cast in the form of 3·25" × 1·25" ×36 — 40" long strip ingot, hot rolled at 480 – 490°C in a 24" 2-high non-reversible up to ·28" thickness and finished cold-rolled in a 18" 2-high non-reversible mill with interstage annealing at 400°—430°C to different thicknesses from 4BG (·238") to 25 BG (0·020") when treated by water-quenching at 500°±5°C and acclerated age-hardened at 180°±5°C in a h.f. oil bath, it exhibited the physical properties of 0·15% proof stress 24·0-25 ton/sq. inch, U.T.S. 28·0-29·0 ton/sq. inch, Elongation 8% B. H. 125-130 from a 20 BG (0·036") strip and 0·15% proof stress 24·0-25·5 ton/sq. inch, U.T.S. 27·5-30·0 ton/sq. inch, Elongation 7·5-8·0% B. H. 130-135 from a 25 BG (0·020") thickness strips.

Contribution of Indian Ordnance Factories, Metal and Steel Factory, Ishapore, O. F. Katni and O. F. Ambarnath

The inverted process of extrusion which has its origin in the extrusion of lead pipes, was first made applicable in the extrusion of copper-base alloys in 1924 following the investigation work carried out at the Research Department of Royal Arsenal Woolwich by R. Genders (L.I.M. No. vol. XXXII, 1924). Following the above investigation, a 900-ton capacity horizontal extrusion press with hydraulic working pressure of $1\frac{1}{2}$ tons per square inch was designed and erected by M/s Henry Berry and Co., Leeds.

This 900-ton extrusion press later on acquired by the Indian Ordnance Factories and installed at Metal and Steel Factory, Ishapore, in the same year made the beginning of manufacturing both lead-free and leaded 60/40 brass extruded rods and sections in sizes varying from 1/4″ to $2\frac{1}{2}$″ diameter and tubes 1/4″ to $1\frac{1}{4}$″ bore. The bore of the receiver was $6\frac{3}{4}$″ diameter and 27″ in length which allows the use of a billet 6-5/8″ diameter and 24″ long.

Later on, extrusion of pure copper, pure aluminium as well as light aluminium alloys of both duralumin and super-duralumin was established at Metal and Steel Factory, Ishapore.

The M. S. F. Press consists of two main cross-heads, one carrying the hydraulic cylinder and arrangement and the other holding the hollow plunger. The two cross-heads were connected by steel columns. These carried the container, which was movable either by means of the main ram by two small auxiliary vicing or stripping rams. The charging arrangement consists of a laterally movable solid block, having attached to one side a cradle for the billet. On centering the cradle with the container a small hand-operated pusher in the hydraulic ram can be used rapidly to charge the billet, and by moving the carriage across the press the solid block or "gag" is interposed between the receiver and the hydraulic ram. The receiver was of the usual jacketed type and was heated by gas-burners.

While the initial small scale production of wrought light aluminium alloys of duralumin type was established at Metal and Steel Factory, Ishapore, and continued up to the end of World War II, it was, however, discontinued later on due to limitations in the working condition of the 900-ton Ishapore Extrusion Press and ancillary facilities for undertaking regular bulk production of this store. Advantages, however, were taken to use the 2000-ton Loewy Extrusion Press which was installed at Ordnance Factory, Katni, during the last World War period, primarily for the production of copper-base alloys—bars, rods, sections and tubes—for small scale production of light aluminium alloys till a complete separate modern aluminium extrusion plant with all ancillary facilities was set up at Ordnance Factory, Ambarnath, in 1960-61. Thus for a period of about 8 to 10 years from 1951-52/1960, wrought aluminium alloys of both not-heat-treated and heat-treated grades conforming to BS : STA 7/AW-8, AW-11 and AW-15 were produced at Ordnance Factory, Katni. AW-8 was primarily used in the manufacture of medium strength components such as fuzes, AW-10 and AW-11 for medium to high strength applications in the manufacture of fuzes and other machined parts and AW-15 for high strength applications only involving severe forming, such as bending, flanging, etc., in the fully treated condition for complicated high duty/high stressed component parts.

Since June 1961, a new integrated extrusion plant complete with melting, semi-continuous casting, a 2000-ton Piercing type Fielding and Plat Hydraulic Extrusion Press, hot and cold draw benches, heat-treatment furnaces, etc., has been operating exclusively for the manufacture of different types of aluminium wrought alloys. Production range comprises bars, rods, sections, tubes, etc., in sizes varying from 10 mm to 80 mm conforming to British Standard 1474, 1475, 1476 and other International Standard Specifications in addition to our own Indian Standards Specifications.

Technical observations

It has been observed that the properties of aluminium alloys are greatly dependent on the initial as-cast condition, which in turn depends on : (a) how the melt has been inoculated to introduce nuclei by addition of Ti, C, B, for obtaining the fine as-cast grain structure or by other transitional metals like Zr, Cr, Mn for producing a fine re-crystallised structure, (b) by effective degasification for efficient removal of excess of dissolved mono-automatic hydrogen from the melt by using C_2Cl_6, Cl_2 or argon, and (c) on the method of casting which may be continuous, semi-continuous or individual ingot moulds, the criteria being cooling rate which varies according to size of casting, the pouring temperature and the arrangement for abstraction of heat. The as-cast state is, however, not a thermodynamically stable state since higher cooling rate may lead to a metastable condition.

For fabrication, the cast products are re-heat-treated for homogenising the structure by taking into solution the constituents outside the primary grain. The working conditions depend on the structural state of the alloy and the temperature used. Thus certain alloys are difficult to extrude on account of large percentage of soluble alloying elements which set up a high resistance to deformation, while some others are quite easy to extrude. The extrusion pressure is dependent on temperature, the composition of the alloy and degree of reduction. It has been observed that wide variation in extrusion temperatures produce different recrystallised structure with different mechanical properties. It is, therefore, essential that proper attention must be paid at each stage of manufacture starting with melting to produce optimum as-cast structure which in turn, may develop proper recrystallised structure after homogenising, extrusion and necessary treatment.

Since most of the wrought aluminium alloy products as manufactured in the Indian Ordnance Factories are in the form of bars and sections as well as extruded round and hollow sections by hot extrusion process, it may be worthwhile mentioning a few lines as to what actually happens during extrusion. A homogenised alloy consists of an assembly of grains and subgrains with intermetallic particles at the boundaries. During extrusion under compressive load and homogeneous shearing actions, the grains are distorted and the components aligned in the extrusion direction following the plastic flow-lines as determined by the shape of the extrusion dies, keeping symmetry with the extrusion axis. Due to strain and high temperature, the grains are hot work-hardened and re-crystallised by developing a complex structure depending on the shape of the extruded product. A careful metallographic examination of extruded stock reveals a central zone of regular oriented texture with a fibrous distribution of insoluble intermetallics surrounded by a peripherial zone which may extend over much of the section of weakly refined texture and an extreme outer zone showing no preferred orientation of the grains but containing finely distributed intermetallics.

In the private sector, Indian Aluminium Company has played a very important role in the development of different types of aluminium alloy products in the country. Their products include plates, sheets, extruded rods, tubes, wires from a wide range of specifications ranging from pure aluminium to work-hardening non-heat-treatable alloys as well as high strength heat-treatable alloys of Al-Cu-Ci-Mg-Mn type. These products find their uses in general structural/architectural parts, electrical fittings, highly stressed parts in several components and in ship-building industries requiring high strength and high corrosion resistance.

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