PROPERTY DEI/EIDPffillt IN EXTRUSION
PROCESSED Al, Mg AND Pb ALLOYS

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1. INIRODUCTION

Extrusion processing is emerging as one of the important mechanical processing techniques since the last couple of decades both in terms of tonnage production and the variety of profiles. Particularly this is so in the field of aluminium alloys which are used as structurals, architectural and other engineering materials including electrical conductors. This is clear from the fact that the production of aluminium extrusions shot up from 22,000 tpy in 1980 to 62,000 tpy in 1990 and increasing at the rate of 10-15% every year. Similarly magnesium-aluminium extrusions in simple and integrated sections are being extensively used in defence and space applications because of their light weight and high strength.

Extrusion processing is also widely employed for lead alloys. Amongst these, commercial alloy B which is lead containing 0.85% antimony is one of the standard alloys used in telecommunication cable sheathing. The significance of good extrusion lies in the fact that the products possess excellent surf ace finish, refined recrystallized grain structure, close tolerance, very good mechanical properties imperviousness to moisture (true particularly to lead alloy B) and longer service life.

None the less quality of extrusion very much depends on a number of parameters like alloy chemistry, temperatures of homogenisation, soaking and extrusion, extrusion speed, lubrication etc. In this talk the influence of some of these on the above three types of alloys will be discussed after a brief account of various extrusion processes in practice.

2. FEATIIES OF EXTRUSION PROCESSING

Amongst the various mechanical processing routes, extrusion is considered very versatile as it offers the following capabilities:

- Numerous profiles of simple and complicated shapes can be produced in a single operation.
- Alloys difficult to work otherwise due to segregation of phases etc can be made (e.g Mg alloys).
- Unique combination of physical and mechanical properties, excellent corrosion resistance, amenability to various surface finishing techniques etc in the products/sections.
- Reduced assembly/joining costs.
- Complete elimination of machining cost.
- Close-fit dimensional tolerance can be obtained.

3. COMMON TYPES OF EXTRUSION

Extrusion can be broadly classified into direct and indirect types. Direct extrusion is the most common and versatile. In this, billet is placed in a container and pushed through the die by the ram. It offers friction between billet and container. Metal flows from the centre of billet and outer skin with impurities flow backward.

In indirect extrusion, die is mounted at the end of hollow ram and the other end of the container is closed. Frequently, in indirect extrusion, the ram containing die is kept stationary while the container with billet is caused to move. In this, there is lesser friction between billet and container as compared to direct extrusion.

Tubes can be produced by extrusion attaching a mandrel (fixed type) to the end of the ram. Floated mandrel is also used with dummy block to achieve uniform wall thickness in direct extrusion. The clearance between the mandrel and die wall determines the wall thickness of the tube.

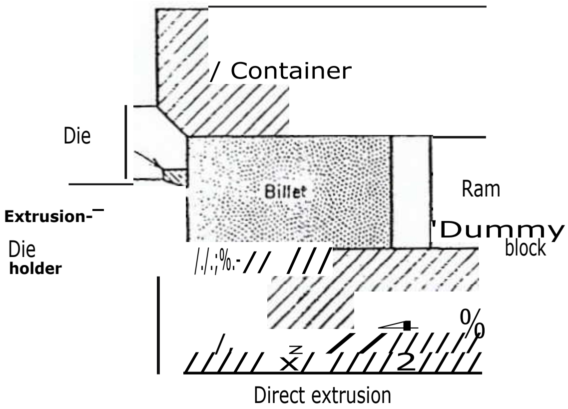
Impact extrusion is another form of indirect extrusion used to form short length of hollow shapes such as collapsible tubes for tooth pastes etc. Schematic sketches of various extrusion processes are shown in Fig .1.

3.1 Billet on Billet Extrusion

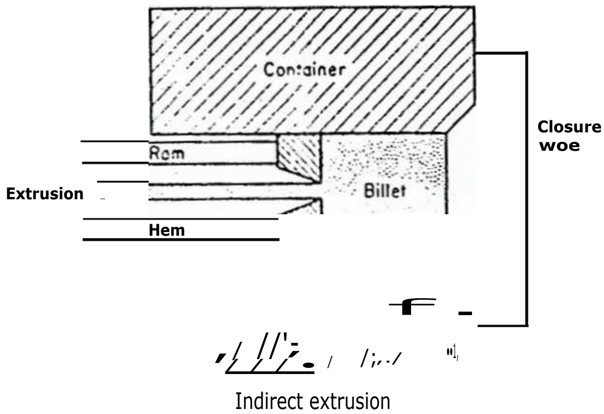
In normal extrusion using a single billet, the discard amounts to 12-14% of the billet length. The technique of extruding without discard is generally referred to as billet on billet extrusion. This produces product of continuous length or non-continuous length as required. It increases recovery by approximately 5-10%. Large number of billets can be put one by one to the container and billet joining takes place during extrusion resulting in producing a continuous length.

3.2 Press Quenching

Quenching facility at die exit end is provided for the aluminium alloys which is required to be age hardened after extrusion. The extrusion temperature of the material in the container is sficient for the alloys to undergo solution treatment and the prod=t needs only artificial aging treatment to get the required mechanical properties. Press quenching is very common in large presses extruding age hardenable aluminium alloys.



(a)



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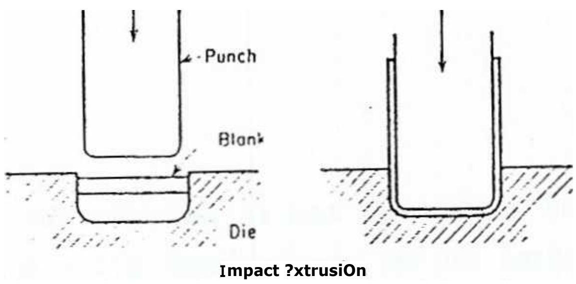


(d)

Fig.1 Shows schematic diagrams of: (a) direct extrusion (b) indirect extrusion (c) impact extrusion.

4. ALUMIME14ALLOYS FOR EXTRUSION

Common aluminium alloys used for extrusion belong to medium strength Al-Mg-Si (6xxx) and high strength Al-Cu (2xxx) and Al-Zn-Mg/ Al-Zn-Mg-Cu (7xxx) series. About 2/3rd of the total aluminium alloy extruded belong to Al-Mg-Si series. This is the situation in India and in the world as well. Al-Mg-Si alloys can be classified into 3 broad groups - first the alloys having stoichiometric composition of Mg_2Si and the second the alloys with Mg_2Si containing excess Mg and the third group is the alloys with Mg_2Si containing excess Si. These alloys cover the full range of ultimate tensile strength from 190 MPa to 320 MPa in the heat-treated condition. With the advances in the technology, it has been made possible to extrude economically some of the very high strength alloys belonging to Al-Cu and Al-Zn- Al-Zn-Mg-Cu system.

4.1 Influence of Heat-treatment on Extrusion of Aluminium Alloys

Heat-treatment schedule of the billet play an important role on the properties of the extruded products. Following aspects will be discussed:

(a) Homogenization of cast billet
(b) Cooling from homogenization temperature
(c) Preheating of billet period to extrusion
(d) Extrusion temperature
(e) Natural and artificial aging of product

Homogenization of Cast Billets:

Homogenization of extrusion billets is an important step and significantly influences extrudability, the surface quality of the section and mechanical properties of the products. Homogenization has three principal functions:

(i) solution and reprecipitation of soluble phases (chiefly Mg_2Si, $MgZn_2$ and $CuAl_2$);

(ii) precipitation of supersaturated phases (chiefly Cr, Mn and Zr bearing compounds);

(iii) spheroidization of insoluble phases (FeA13, 04 and p AlFeSi).

The extent to which these functions are achieved depends on the time and temperature of soaking and on the rate of heating and cooling.

If the extrudability of the as-cast and properly homogenized billets are compared, it will be found that homogenized billets can be extruded upto 40% faster than the as-cast billet. Also the tendency of edge cracking is found to be significantly reduced in homogenized billets with the mechanical properties of the products improved. An example of this is given in Fig.2 in which 2(a) shows the correlation of extrusion power and content of alloying elements in as-cast and homogenized billets of Al-Mg-Si alloy and 2(b) shows the influence of homogenization temperatures in Al-Mg-Si containing Fe on the ultimation tensile strength.

Cooling from Homogenization Temperature:

Rate of cooling from homogenization is equally important as it offers good extrudability and excellent section quality. Fig.3 shows the variation of extrusion power with amount of Mg_2Si in the Al-Mg-Si alloy in different cooling conditions.

Preheating of Billets to Extrusion Temperature:

Fig.4 shows that induction furnace preheating and gas furnace preheating result in different working conditions of the billets.

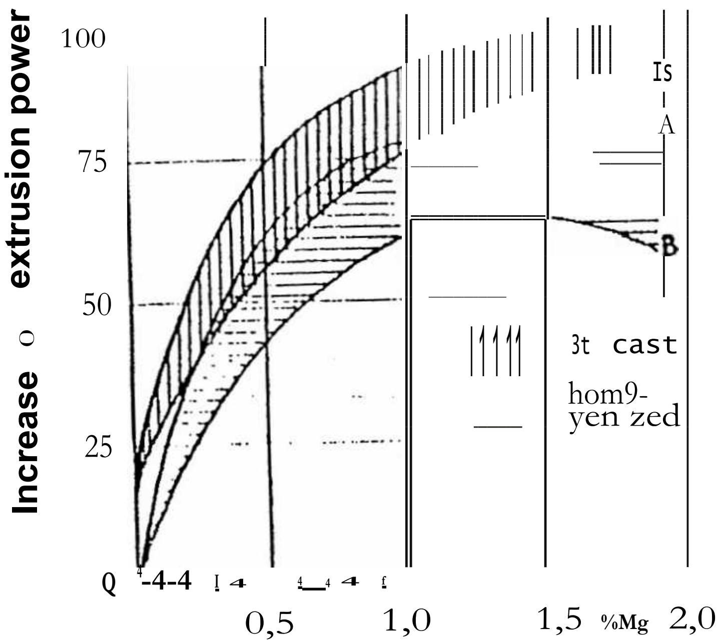


Fig.2(a) Shows effect of Mg content on extrusion pressure of AlMgSi alloy billets in as-cast and homogenized/WQ condition:
tV• = AlMgSi alloy with 0.1% excess Mg
B = AlMgSi alloy with 0.3% excess Si

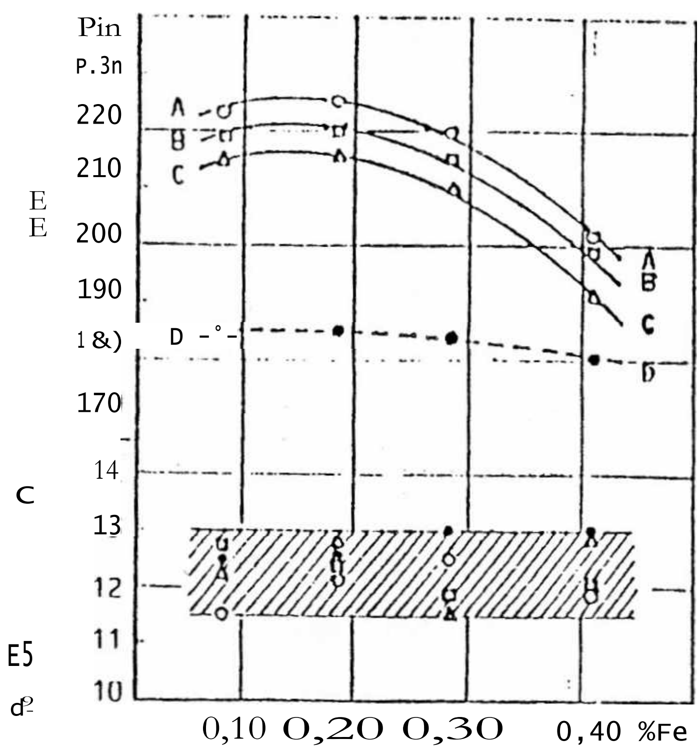


Fig.2(b) Shows effect of homogenization temperature on tensile strength of AlMgSi 0.5 extruded product with varying Fe content
A = 580°C homogenizing temperature
B = 550'C -do-
C = 520°C -do-
D = 450°C -do-

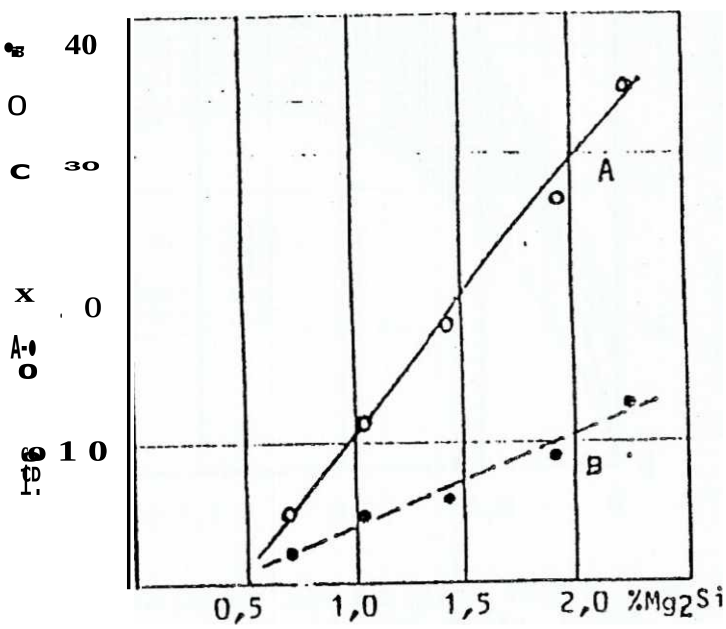


Fig.3 Shows effect of cooling rate after homogenization of AlMgSi alloy billets with varying Mg_2Si content on extrusion power
A = 585°C/12 h/WQ; B = 585°C/12 h/AC.

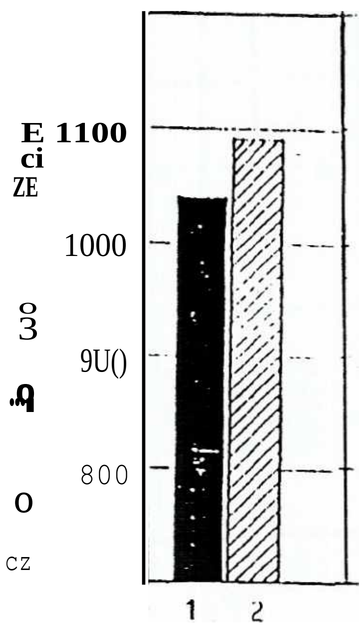


Fig.4 Shows effect of preheating on deformation work of AlMgSi 0.5 billet. Homogenized 580°C/6 h/WQ: 1 Preheating to 485°C in induction furnace for 2 min; 2 preheating to 485°C in gas fired furnace.

Whilst fast preheating does not change the structure of the homogenized billet, the slow preheating rate in gas fired furnace can cause a high degree of dissolution of Mg_2Si particles rsulting in high yield strss combined with lower productivity.

Extrusion Tmperature:

Due to deformation and friction between billet and container in direct extrusion and high ram speed, temperature of the metal rises. Rise in temperature can be partly extracted by the container wall and the die. Degree of rise of temperature depends on the preheating condition and the type of the alloy composition as well. Fig.5 shows limiting temperature for hot cracking of some Al alloys.

Natural and Artificial Aging:

Al alloys subjected to press quenching require only artificial aging after extrusion because during press quenching, the alloys have undergone the solution treatment operation. Some aluminium alloys (AlHMg-Si, Al-Zn-Mg) undergo natural aging and part of the full strength can be achieved on storage at room temperature. Other alloys need to be artificially aged at suitable temperatures for getting the properties. Figs.6 and 7 show effect of natural and artificial aging of rod of Al-Mg-Si alloy respectively after extrusion.

5. Al.-Zn-Mg AUDY lE:music:vs

High strength aluminium alloys based on Al-Zn-Mg system are adopted by the structural engineers for light weight construction for civil and defence application on account of their high strength to weight ratio and excellent weldability. Table-I shows details of extrusion parameters of weldable Al-Zn-Mg alloy. It can be noted that

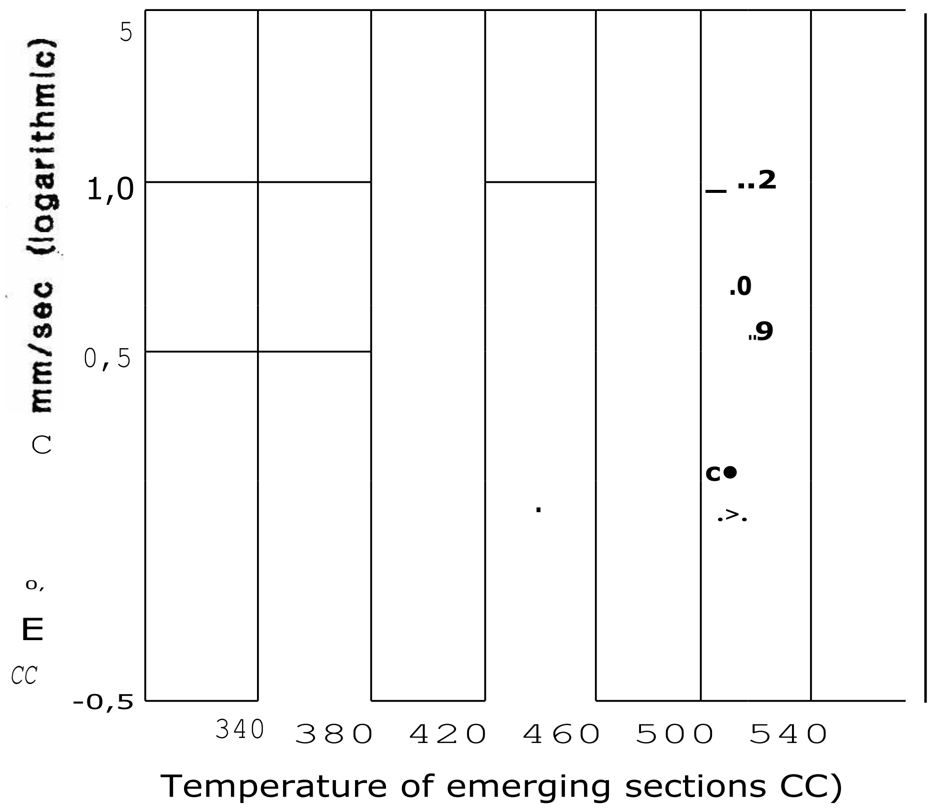


Fig.5' Shows hot cracking limit curves of different Al alloys.

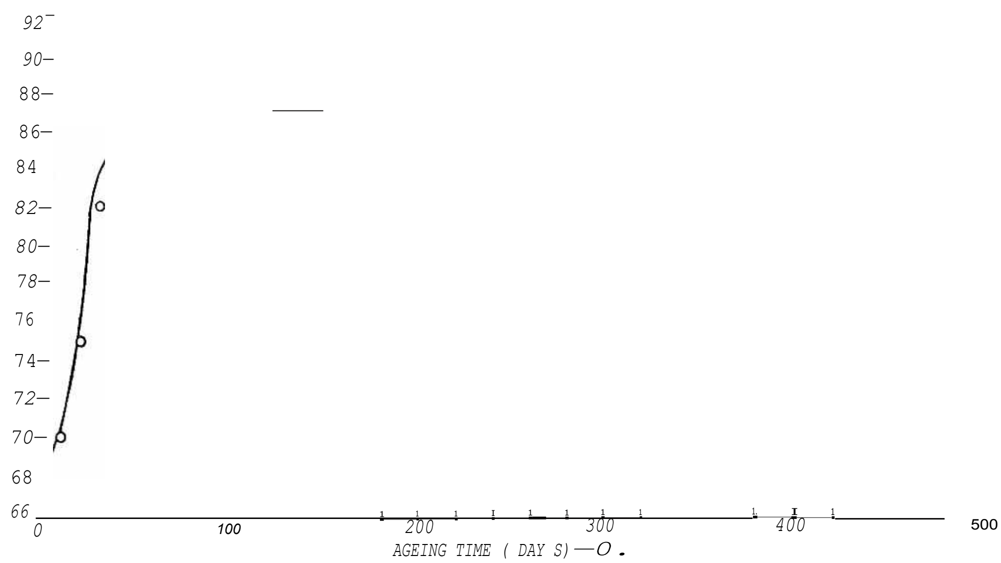


Fig.6 Shows natural aging of Al-Mg-Si wire rod (9.5 mm dia) after press quenching.

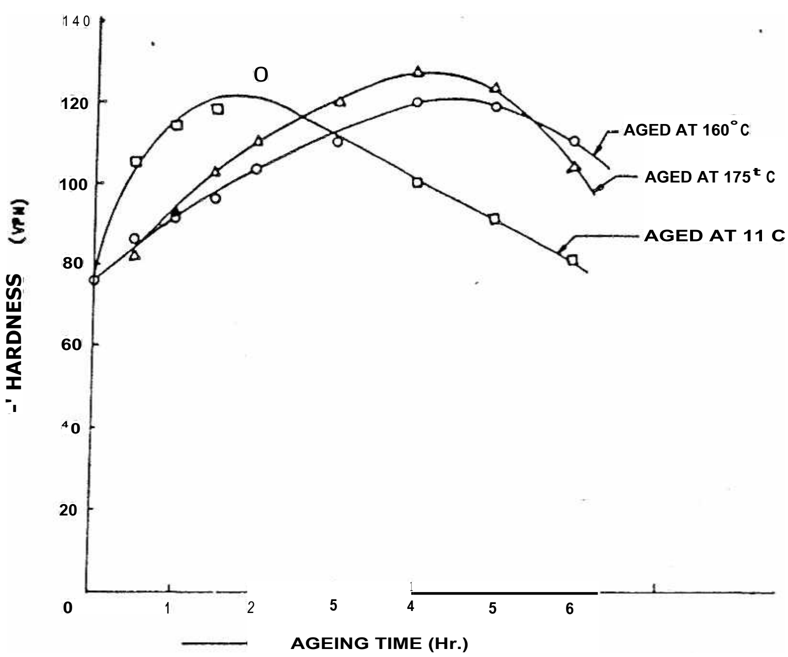


Fig.7 Shows effect of aging time and temperature on hardness of Al-Mg-Si alloy extruded rod (19 mm dia).

fibrous structure has been developed both in the front and back end favourable for high stress corrosion resistance under conditions of extrusion speed of 15 mm/sec and cooling rate of 0.45°C/sec (extrusion No.A-4 and A-6).

Table I: Details of extrusion parameters of weldable Al-Zn-Mg alloy

Extrusion Number	Reheating furnace temp. (°C)	Billet temp. as it enters the container (°C)	Extrusion speed (mm/sec)	Cooling rate of product (°C/sec)	Microstructure
A4	470	441	15	0.45	Fibrous
A6	450	427			
AS	490	488	22	0.32	Partially recrystallized
Al	490	482			
A2	490	482			
A3	470	441	22	0.65	Partially recrystallized
A5	450	440			
A7	490	482			
A9	480	454	27	0.72	Fully recrystallized

6. EXTRUSION OF wicaffsium BASE ALLOYS

6.1 Magnesium Alloys for Extrusion

Magnesium alloys commonly used for extrusion belong to Mg-Al-Zn system (AZ, AZ 31 B, AZ 61 A, AZ 80 A) and Mg-Zn-Zr system (ZK 60 K).

6.2 Features of Magnesium Extrusion

Extrusion of magnesium alloys is very similar to the extrusion of aluminium alloys. However, extrusion speed is generally kept lower for magnesium alloys than for aluminium alloys to avoid speed cracking that results from hot shortness. Also incipient melting of certain phases can cause tearing during the extrusion processing of Mg alloys. Frictional forces in the extrusion process is the principal cause which leads to incipient melting and hot shortness. Therefore, the extrusion speed must be controlled so that the amount of heat generated during extrusion is not too high. However, it is important to increase the extrusion speed without sacrificing the mechanical properties. In order to achieve this, the temperature rise during processing should be kept as low as possible by employing proper lubricants of die (e.g grease + graphite, grease + graphite + MoS_2), proper homogenization of billet and lower billet temperatures.

6.3 Heat-treatment of Extruded Products

Both cast and wrought magnesium alloy products are heat-treated in practice to alter the mechanical properties. Three basic types of thermal treating processes are commonly used for magnesium alloys. These area

solution heat treatment
aging
annealing

In addition, stabilizing and stress-relieving treatments are also used in practice.

Solution heat-treatment consists in heating the alloy to a temperature at which certain constituents go into solution, and then quenching so as to hold these constituents in solution during the cooling. Quenching is done in stilt air/moving air, liquids not ordinarily being used. For Mg-alloys the solution heat-treatment temperature Lies in the range of 345-420°C and holding period is 16 to 24 hours.

Aging treatment consists in heating the quenched alloy at a moderately elevated temperature to effect the precipitation of the constituents held in solid solution. The temperature of heat treatment lies in the range of 150-205°C, exposures from 3 to 16 hrs. Both temperature and time depend upon the composition and other factors.

Annealing consists in heating the alloy at a moderate temperature (about 340°C) to effect recrystallization, agglomerate precipitate or remove internal stresses.

6.4 Extrusion of Mg--6Al-Zn Alloy

At NML extrusion of AZ 61 alloys (Mg-6A1-1Zn-0.4Mn) was successfully done to get various sections like T, V and L shapes, tube and rounds. Table-II gives the details of the extrusion parameters for this alloy. Fig.8 shows the variation of hardness with aging time of the AZ 61 alloy. Table-III gives the mechanical properties attained in as-extruded and after ageing treatment. Fig.9 shows effect of lubricant and extrusion temperature (a) grease + MaS2, (b) inadequate lubrication, (c) fir-tree-type due to high extrusion temperature. Fig.10 shows good extruded sections of AZ 61,

7. EXTRUSION OF lEAD-ANTDDNY ALLOY

Pb-0.85Sb alloy is commonly used for cable sheathing and is produced by direct extrusion around a cable core at temperature not harmful to the insulation. However, there is tendency for developing cracks during extrusion if proper extrusion parameters are not controlled. Fig.11 shows schematic diagram of the vertical extrusion press used for manufacture of cable sheathing.

Table II: Details of extrusion parameters of Mg-6A1-1Zn alloy

Expt. No.	Soaking temp.(°C)	Time (mins)	Container temp.(°C)	Extrusion parameters Ratio	Speed m/min	Pressure kg/mm2	Extruded shape	Remarks
1.	340	60	300	17	18	45	19 mm dia	High temp. failure (fir-tree type)
2.	300	180	280	17	18	40	-do-	High temp. defects
3.	280	180	270	17	18	45	-do-	Surface cracks
4.	280	60	260	17	12	56	-do-	Very good product
5.	270	75	260	17	12	52	-do-	-do-
6.	280	120	250	17	1	12	120 mm dia	Good product
7.	280	150	250	17	1	11.5	-do-	-do-
8.	320	60	300	25	24	55	32mm x 6mm rectangular	High temp. failute
9.	280	30	280	25	24	55	-do-	Good product
10.	250	60	250	25	24	55	-do-	-do-

Table III: Mechanical properties of Mg-6A1-1Zn in as-extruded and heat-treated conditions

Condition	UTS I (MPa)	% elongation (50 mm GL)
As extruded (as per specification)	260	8
As extruded	270	8 to 10
Extruded and heat-treated at 420°C, 6 hrs	260	12 to 15
Extruded and heat treated at 420°C, 3 hrs	260	12 to 15

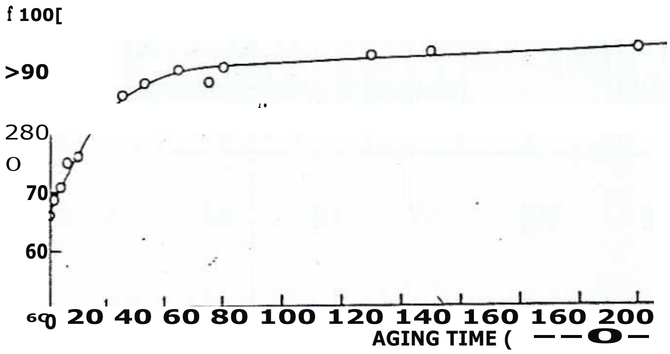


Fig.8 Shows variation of hardness with aging time of extruded product of AZ 61 alloy (Solution treatment 415°C/3 hrs/WQ, aging 175°C).

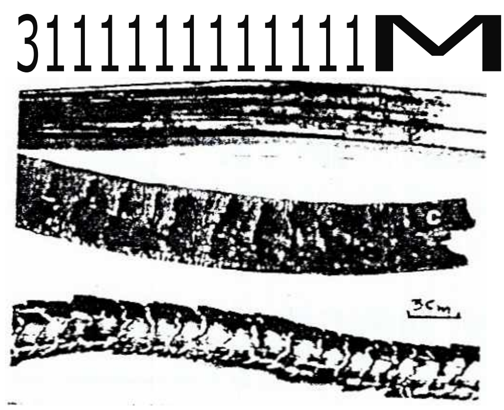
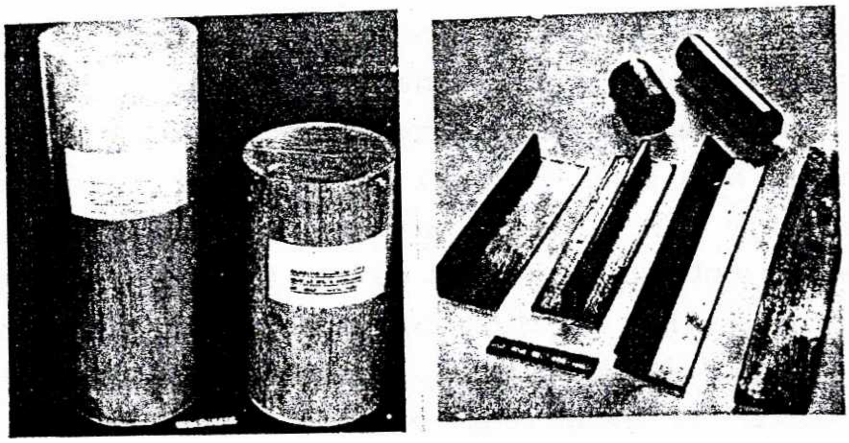


Fig.9 Shows effect of lubricant and extrusion temperature (a) lubricant grease + MOS_2, (b) inadequate lubrication, (c) fir-free-type failure due to high extrusion temperature.



Flg.10 Shows various defect free extruded sections of AZ 61.

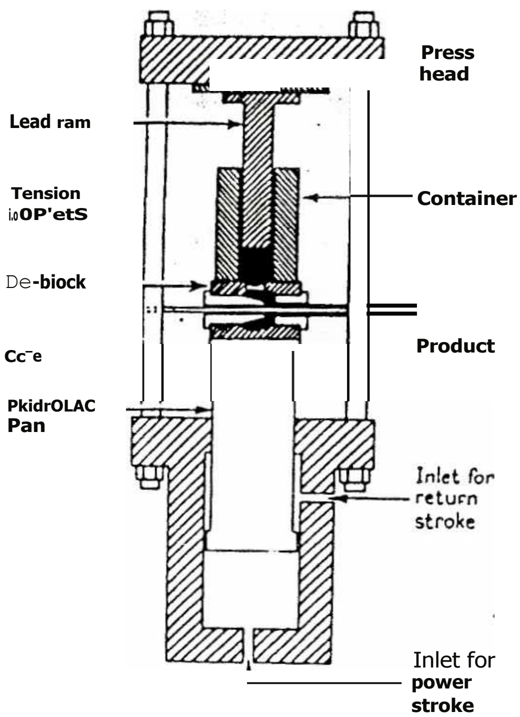


Fig.11 Shows schematic diagram of the vertical extrusion press for cable sheathing.

7.1 **Production of Pb-0.85Sb Cable Sheathing**

About 400 kg of Pb-0.85Sb melt is transferred to the container maintained at 450+10°C through a chute. After removing the dross, the ram of 2250 T press touches the upper surface of the melt. The ram is brought down at a pressure of 100 kg/cm^2 on the top surface of the melt and kept for 5 minutes prior to extrusion operation. The container is cooled by an external cooling jacket in order to speed up the solidification of the melt. Extrusion is subsequently carried out at a pressure of 460 kg/cm^2 using an electrically heated die block. The temperature of the different zones of the die block is generally maintained in the range of 170-220°C by thermostatic control. Normally, extrusion speed of 15-20 m/min is employed. After the extrusion, the product is passed through a water trough in order to cool the sheathed cable and finally coiled in a reel. Failure sometimes occurs immediately after extrusion and/or during the reeling operation.

7.2 A, **Case Study of Failed Extruded Cable Sheathing**

Uniformity of die temperature is an important factor for good extrusion of consisted thickness and smooth crack free surface. The investigation results are presented in Tables-IV, V and VI and Fig.12.

Table rV: Temperature of different zones of the die-block

Location	Temp.(°C) I	Temperature gradient (°C)
Top right	160-165	50
Bottom right	210-215	
Top left	170-180	45
Bottom left	215-225	

Table V: Variation in the wall thickness of failed and good sheaths

Sample	Nominal outer dia (mm)	Wall thickness (mm)	
		Thinnest	Thickest
Failed. No.1	34	2.4	3.0
Failed No.2	22	1.0	2.4
Failed No.3	22	1.1	2.1
Good	34	2.9	3.2

Table VI: Grain size measurement of failed/good sheaths

Sample	Average grain size (microns)
Failed sample	55-75
Failed (thick wall)	65-85
Failed (thin wall)	50-60
Good	55-65

7.3 Important Parameters in Extrusion of Pb-0.85Sb Alloy Cable Sheathing

Control of extrusion temperature is of utmost importance in th production of sound sheathing. The die block temperature may be controlled to maintain a gradient of 20-25°C between the upper and lower halves of the die block. Temperature of the upper die block should be maintained at 160-165°C while the lower die block may be maintained at 180-185°C. Use of scale forming water for cooling die should be avoided. Descaling at regular interval should be done.

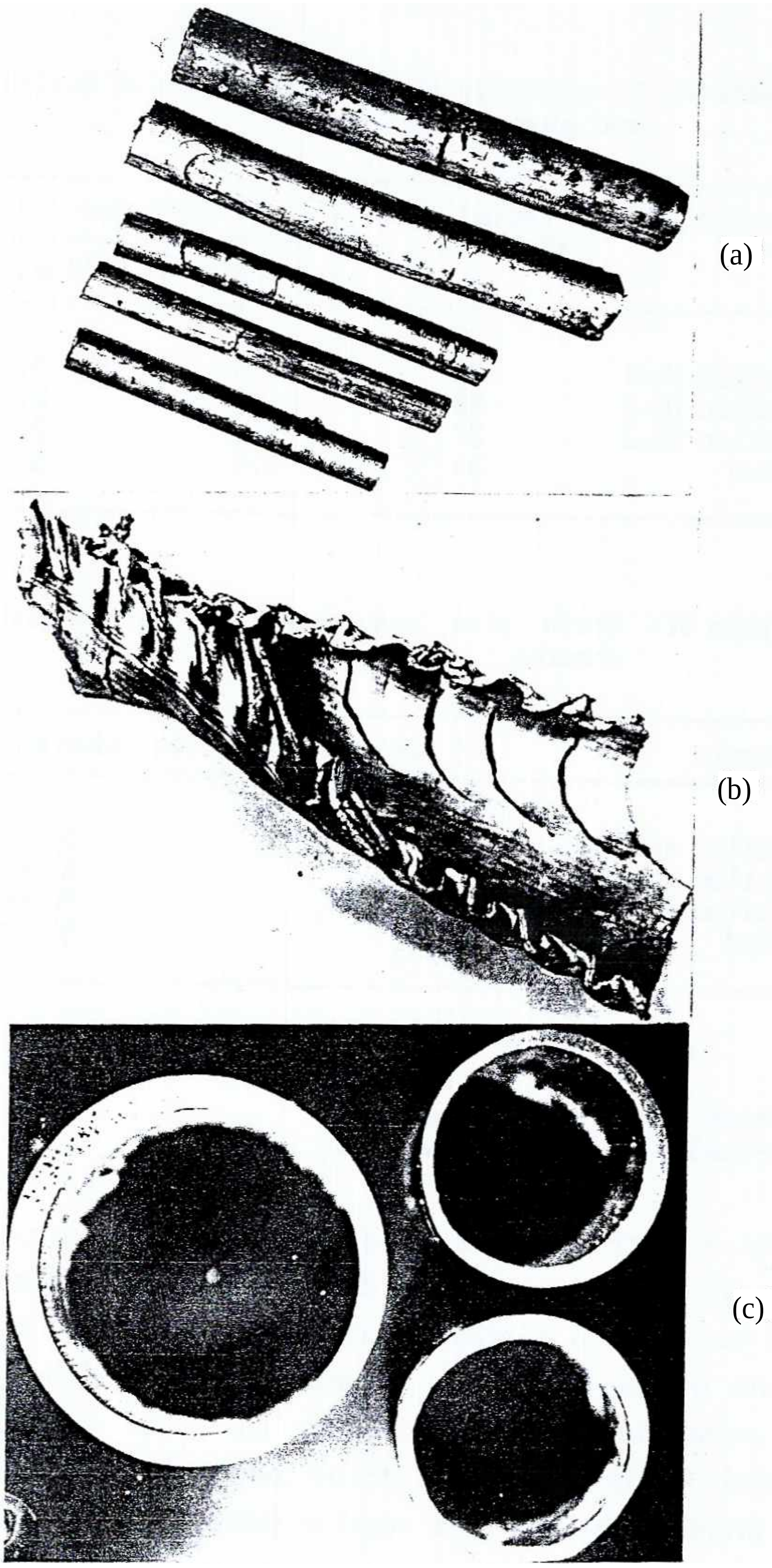


Fig.12 Shows typical defects (a) circumferential cracks, (b) ripples/ridges on the outer surface of the sheath, (c) non-uniform wall thickness.

8. CONCLUSIONS

On account of inherent superiority and versatile nature, extrusion processing is being widely used for non-ferrous alloys. By proper control of alloy composition, extrusion parameters during processing and thermal treatments of the products, mechanical and other properties can be significantly improved.

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BD3LIOGRAF'HY

1. G.E.Dieter, "Mechanical Metallurgy", McGraw Hill Book Co., 1976, 514.

2. C.E.Pearson, 'Extrusion of Metals", John Wiley and Sons Inc., New York, 1960.

3. T.Sheppard, S.J.Paterson and M.G.TUtcher,"Microstructural Control in Aluminium Alloys", Ed. E.H.Chia and H.J.MCQueen, Met.Soc.Inc. 1986, 123.

4. K.Lal and R.Kumar, Proc. INCAL-85, Ed. V.R.Subramanian, Delhi, October 1985, 724.

5. K.Lal, A.K.Bhattamishra and R.Kumar, Prof. Aluminium Contress II, National Alliance of Young Entrepreneures and Aluminium Association of India, Delhi, January 1985, IX 4:1.

6. G.D.Sani, Kishori Lal, B.K.Saxena and Rajendra Kumar, Proc. Non-ferrous Semis and Products, New Delhi, IIM Delhi Chapter, 1980, 415.

7. J.Langerweger, "Aftuminium-1986", Ed. T.Sheppard, The Inst. of Metals, 1986, 216.

8. Scott O.Shook, Proc. 49th Annual World Conf. on 'Magnesium on the Move', Chicago, Illinois, USA, May 1992, 44.

9. E.F.Emley, "Principles of Magnesium Technology", Pergamon Press, Oxford, 1966.

10. B.Kittilsen, Proc. 'Magnesium Technology', London, The Inst.of Metals, November 1986, 36.

11. S.A.Hiscock, Lead and Lead Alloys for Cable Sheathing, Ernest Benn Ltd., London, 1961, 58.

12. Lead 1971, Proc. Fourth Inter. Conf. on Lead, Lead Development Association, London, 1971, 49.