Design & development of Aluminium alloy extrusion for structural application.

Girish JR
M/s Engineers' Citadel, Bengaluru. (MIE – M137965)

***Abstract*- This paper attempts to present a comprehensive methodology for the design and development of a new aluminum alloy extrusion, for structural application, from initial concept to final product validation. The process is outlined as a series of integrated steps, beginning with the design of sectional profile to meet application requirement, material selection, derivation of Mechanical properties of the section, calculation of loads for a structural assembly, structural analysis & die design considerations. This paper tries to provide a valuable guide for engineers to design efficient and optimal extruded components for structural applications. Here a typical Solar PV Module mounting structure is used as an example to demonstrate the steps involved.**

***Index Terms*- Aluminium alloy, solar module mounting structure, area moment of inertia, section modulus, extrusion, wind loads, Solar PV power plants.**

***Notations*- 1. PV Module: Solar Photo Voltaic Module**

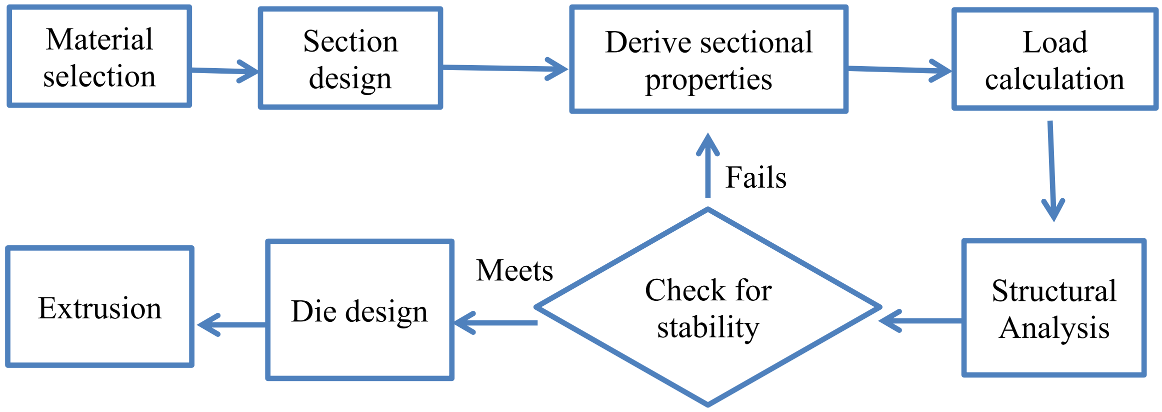
I. INTRODUCTION

Aluminum is alloyed with copper, magnesium, zinc and / or silicon to have a superior combination of strength, light weight and corrosion resistance, making them ideal for a wide range of structural applications. The extrusion process is a metal-forming technique that involves forcing a billet of heated aluminum alloy through a shaped die to create a product with a specific cross-sectional profile. This process is highly versatile and can be used to produce complex shapes with tight tolerances, making it a preferred method for manufacturing structural components, which can be easily assembled using suitable fasteners.

The development of new aluminum alloys and extrusion techniques has led to significant advancements in various industries, including aerospace, automotive and construction. In aerospace, high-strength aluminum alloys are used to manufacture lightweight air-frames, wings and other critical components, improving fuel efficiency and performance. In the automotive sector, extruded aluminum profiles are used to produce lightweight chassis, bumpers and body panels, enhancing vehicle safety and reducing emissions. In construction, extruded aluminum sections are used to create durable and aesthetically pleasing building facades, window frames and structural supports.

This paper explores in detail the process of development of a special purpose aluminum alloy extrusion for structural applications, particularly for Solar PV Module mounting structure. It delves into the selection of suitable aluminum alloy, design of extrusion section to meet its intended purpose, the design requirements of extrusion process, fasteners requirement for assembly and structural strength requirements to withstand the external loads after assembly, as per applicable IS codes. The process steps presented in this paper contribute to a better understanding of the methodology to be followed in design of Aluminium alloy extrusion components, factors influencing the performance of such components, paving the way for the design and manufacturing of more efficient, reliable and sustainable structural solutions.

II. EXTRUSION DEVELOPMENT FLOW CHART



III. MATERAIL SELECTION

Selection of Aluminum Alloys for Structural Applications (as per Indian Standards)

The selection of an appropriate aluminum alloy for a structural application is a critical step guided by Indian Standards (IS) codes. The Bureau of Indian Standards (BIS) issues these codes to specify the composition, properties, and manufacturing requirements for aluminum alloys and products. For the development of extruded sections for structural use, several key standards are essential:

IS 733: Wrought Aluminium and Aluminium Alloy Bars, Rods and Sections for General Engineering Purposes. This is a fundamental standard for extruded products. It covers wrought aluminum and aluminum alloy bars, rods and sections used for a wide range of general engineering applications. The standard specifies essential mechanical properties, including tensile strength, elongation and hardness, ensuring the material's durability and suitability for load-bearing applications.

IS 8147:1976 (Reaffirmed 2021) - Code of Practice for Use of Aluminium Alloys in Structures.

This code is the guide for the design and construction of aluminum structures. It provides comprehensive guidelines for calculating design loads, permissible stresses and general fabrication practices. It serves as a foundational document for structural engineers, outlining principles for designing tension and compression members, beams and various types of joints (bolted, riveted, and welded).

IS 1285:2023 - Wrought Aluminium and Aluminium Alloys-Extruded Round Tube and Hollow Sections for General Engineering Purposes.

This is a more specific and recently updated standard that is highly relevant for the extrusion process. It details the chemical composition, mechanical properties and dimensional tolerances for extruded round tubes and hollow sections. The standard also specifies the requirements for different temper designations (e.g., T4, T5, T6), which are achieved through specific heat treatment processes and are fundamental to defining the final strength and ductility of the component.

IS 6051:1970 - Code for Designation of Aluminium and its Alloys.

This code provides the system for designating aluminum and its alloys in India. The system classifies alloys into series based on their primary alloying elements, for instance, the 6xxx series (aluminum-magnesium-silicon) is a popular choice for structural extrusions due to its excellent combination of strength, corrosion resistance and weldability.

Commonly Used Structural Alloys and Their Properties:

For structural applications, alloys from the **6xxx series** are commonly chosen due to their excellent balance of properties. These alloys use magnesium and silicon as the primary alloying elements.

6063: This alloy is favored for its excellent extrudability, making it suitable for creating complex and intricate shapes. When heat-treated to the **T6 temper**, it offers good moderate strength, high corrosion resistance and a smooth surface finish. It is often used for architectural and decorative structural elements like window frames and building facades.

6351: With a higher manganese content than 6063, 6351 provides superior strength and toughness, particularly in the **T6 temper**. It is the preferred choice for applications requiring a higher load-bearing capacity, such as heavy-duty structural beams, girders and other engineering components.

By following these Indian Standards, engineers and manufacturers can systematically select and verify the material properties of aluminum alloys, ensuring that the extruded sections are safe, reliable and durable for their intended structural applications.

Example : Selection of material for the Solar Module mounting structure.

The aluminum alloy of grade 6063 T6 is selected for solar module mounting structures, based on a combination of critical properties that are ideal for outdoor, long-term applications. Here is a brief explanation:

Excellent Strength-to-Weight Ratio: The T6 temper, which is a result of a specific heat treatment and artificial aging process, significantly increases the alloy's strength. This makes 6063 T6 strong enough to withstand substantial environmental loads like high winds and snow without being excessively heavy. The lightweight nature of aluminum is crucial for reducing the structural load on rooftops and simplifying transportation and installation.

Superior Corrosion Resistance: Solar structures are constantly exposed to harsh weather conditions, including rain, humidity, and, in some cases, a salty marine atmosphere. Aluminum 6063 has inherent corrosion resistance due to the formation of a protective, self-healing oxide layer on its surface. This natural resistance can be further enhanced with anodization, a common surface treatment that provides a durable, aesthetically pleasing finish and extends the material's lifespan to well over 25 years—matching or exceeding the lifespan of the solar modules themselves.

Outstanding Extrudability: The 6063 alloy is often called an "architectural alloy" because of its excellent extrudability. This property allows manufacturers to produce complex, intricate cross-sectional profiles with tight tolerances. These customized profiles are essential for creating specialized mounting rails, clamps and brackets that allow for easy and secure installation of solar panels.

Cost-Effectiveness: 6063 is a widely available and relatively low-cost aluminum alloy. Its ease of extrusion and processing reduces manufacturing costs, making it an economically viable choice for large-scale solar projects where cost is a major factor. The durability and low-maintenance nature of the material also contribute to a lower total cost of ownership over the structure's lifetime.

In summary, 6063 T6 provides the perfect balance of strength, lightweight design and superior corrosion resistance, all while being a cost-effective material. These characteristics make it the go-to material for ensuring the long-term reliability and structural integrity of solar module mounting systems.

Properties	**Aluminum - 6063 - T5**			**Aluminum - 6063 - T6**	
Density	2.7 g/cc			2.7 g/cc	
Hardness, Brinell	60	Typical; 500 g load; 10 mm ball		73	Typical; 500 g load; 10 mm ball
Ultimate Tensile Strength	186 MPa	Typical		220 MPa	Typical.
Tensile Yield Strength (0.2% proof stress)	145 MPa	Typical		172 MPa	Typical.
Elongation at Break	12 %	Typical; 1/16 in. (1.6 mm) Thickness		12 %	Typical; 1/16 in. (1.6 mm) Thickness
Modulus of Elasticity	68.9 GPa	Typical		68.9 GPa	Typical
Ultimate Bearing Strength	-	-		434 MPa	Edge distance/pin diameter = 2.0
Bearing Yield Strength	-	-		276 MPa	Edge distance/pin diameter = 2.0
Poisson's Ratio	0.33			0.33	
Fatigue Strength	68.9 MPa	500 M cycles, reversed stress, RR Moore specimen.		68.9 MPa	500 M cycles, reversed stress, RR Moore specimen.
Machinability	-	-		50 %	0-100 Scale of Aluminum Alloys
Shear Modulus	25.8 GPa			25.8 GPa	
Shear Strength	117 MPa	Typical		152 MPa	Typical
Electrical Resistivity (Ohm-cm)	3.16e-6	Typical at 20°C		3.32e-6	Typical at 20°C

IV. SECTION DESIGN

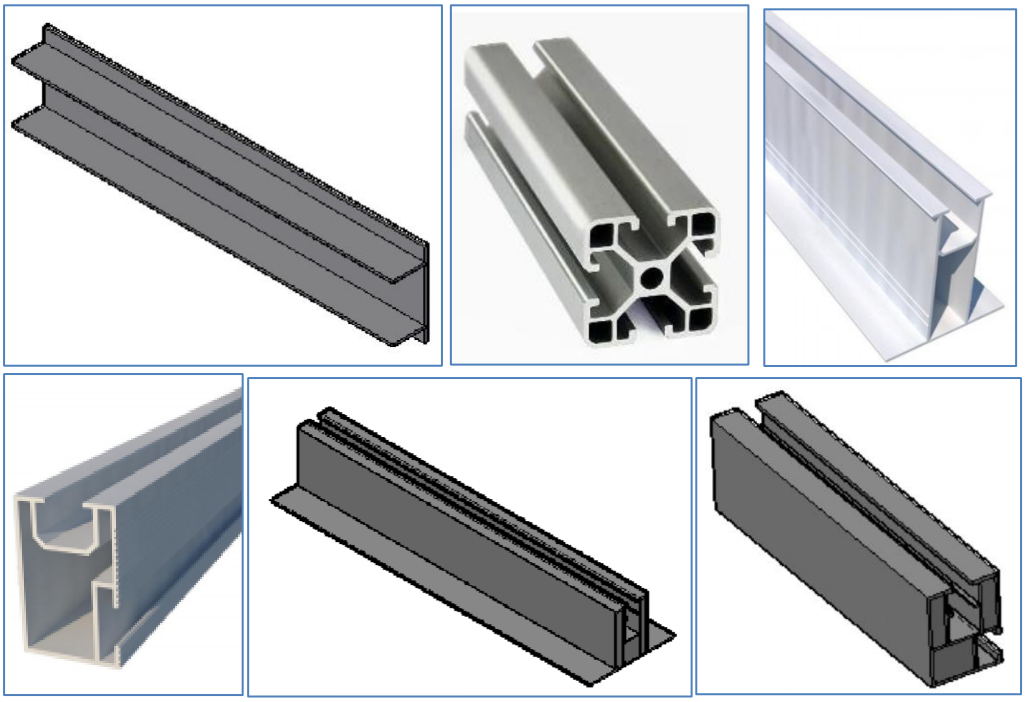
The design of an aluminum extrusion section requires careful consideration of several key parameters to ensure it meets functional, manufacturing, and cost requirements.

Key Design Parameters for Aluminium Extrusion Sections

Functional Requirements:

1. Should meet the requirement of assembly or fixation. In the example considered here, for the purpose of using it as a structure for mounting Solar Modules, provision should be ensures for strong fixation & provide sufficient space for ventilation & access for maintenance.

Few examples of section of extrusions used for this application:



2. Corrosion resistance of the structure material is a critical parameter as the working life of such Solar installations are more than 25 years.

Geometric & dimensional Requirements:

Wall Thickness: The thickness of walls and ribs, which must be thick enough for structural integrity but thin enough for efficient extrusion. Uniform wall thickness is often preferred to prevent warping.

Cross-Section Complexity: The intricacy of the profile, including the number of hollows, voids, and sharp corners. Complex designs may require more advanced dies and can be more costly.

Tolerances: The required dimensional precision of the final product. Tight tolerances can increase die costs and reduce extrusion speed.

Corner Radii: The inner and outer radii of corners. Sharp corners are difficult to extrude and can lead to stress concentrations, so generous radii are preferred.

Manufacturing & Process requirements:

Extrudability: The ease with which the chosen alloy can be pushed through the die. Alloys like 6063 have excellent extrudability, making them suitable for complex shapes. If the section has more closed hollow sections, to create that, more number of mandrels would be required in extrusion machine, which is a critical parameter to consider.

Die Design: The feasibility of designing and manufacturing a die that can produce the required cross-section without premature failure. The complexity and longevity of the die are major cost factors.

Post-Extrusion Processes: Requirements for subsequent operations like heat treatment (T6, T5), cutting, machining, and surface finishing (e.g., powder coating, painting, anodizing). If anodizing is required, then the extrusion should not accumulate the process liquid & enable draining during process.

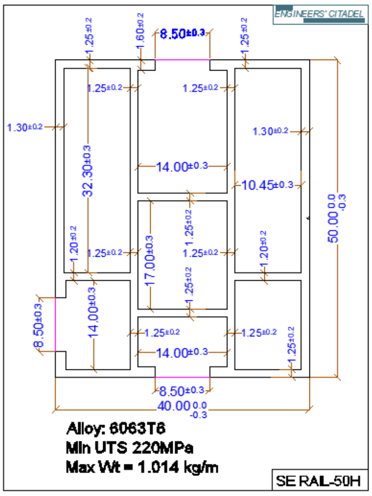
Ease of assembly : The standard fasteners available should be able to be used for assembly. If any special fastener is used, the same be manufacturable in drop-forging or any other mass production methods.

Cost and volume of production:

Tooling Cost: The cost of designing and manufacturing the extrusion die, which is a one-time expense but a significant initial investment.

Production Volume: The number of parts to be produced. Extrusion is most cost-effective for high-volume production runs.

Note: In this example, following section is considered, which meets all the selection requirements:



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Selection note : The section is finalized after consideration of all above points for a specific application of solar PV module-mounting.

MOC : Aluminium alloy as per 6063-T6, minimum UTS of 220MPa.

Fastener : M8 fasteners with Square & Hexagonal head bolts shall be suitable.

Section size : About 50mm high & 40mm wide, which can be extruded by most extruders in India.

Post process : Suitable for Powder coating, Anodizing & liquid painting.

V. DERIVE THE MECHANICAL SECTIONAL PROPERTIES

Mechanical sectional properties are fundamental to the design of an extruded part because they directly dictate its structural performance and functionality. Extrusion is a process that creates a constant cross-section along the length of a material, and the geometry of this cross-section is what gives the part its specific mechanical characteristics.

Sectional Properties of a structural member :

These are the key sectional properties of a typical structural section, used in engineering calculations and design:

Area (A): The total cross-sectional area of the part. It's used in calculating tensile and compressive stresses, as well as the overall weight of the extrusion.

Centroid ($\bar{x}$, $\bar{y}$): The geometric center of the cross-section. All area calculations are typically made with respect to the centroidal axes.

Moment of Inertia (Ix, Iy): A measure of a section's resistance to bending about a particular axis. A higher moment of inertia indicates greater resistance to bending and deflection. For a cross-section, the moments of inertia about the x and y axes are calculated as: $I_x=\int y^2 dA$ $I_y=\int x^2 dA$

Section Modulus (Sx, Sy): This property is used to calculate the maximum stress in a bending member. It is the moment of inertia divided by the distance from the centroid to the extreme fiber of the section. A larger section modulus indicates a higher bending strength. $S_x = I_x / c_x$. $S_y = I_y / c_y$,

where cx and cy are the distances from the neutral axis to the outermost point of the cross-section in the x and y directions, respectively.

Radius of Gyration (rx, ry): This property is used in column buckling calculations. It represents how the cross-sectional area is distributed around the centroidal axis. A larger radius of gyration indicates a greater resistance to buckling.

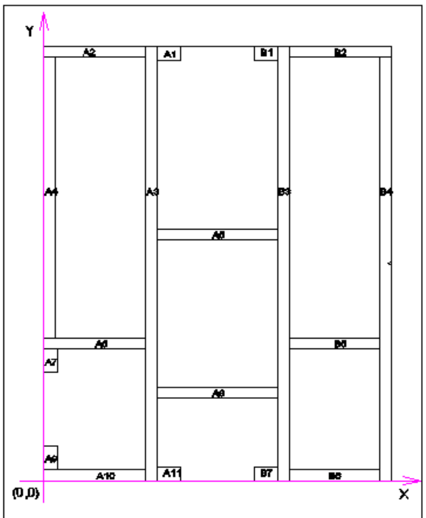
$r_x=\sqrt{I_x/A}$

$r_y=\sqrt{I_y/A}$

Torsional Constant (J or K): A measure of the section's resistance to twisting. For non-circular sections, the calculation of this property is complex and often requires numerical methods.

Shear Center: The point in the cross-section through which a transverse load must pass to cause pure bending without any twisting. This is particularly important for asymmetrical sections.

Derive the CG of the section: Divide the section into number of uniform regular areas. Calculate the CG of the section by equating the area moments about X-axis & about Y-axis.



For CG

Mechanical Properties: Centre of Gravity, Y - axis

Moments about bottom edge as X - axis & bottom LH corner as origin:

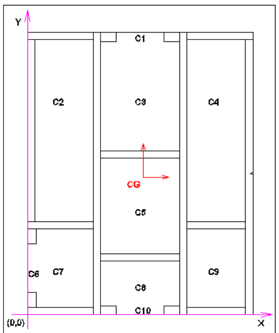
Part	L	B	Area	Dist of area CG from origin (Y)	Moment
A1	2.75	1.6	4.400	49.200	216.480
A2	11.75	1.25	14.688	49.375	725.195
A3	1.25	50	62.500	25.000	1562.500
A4	1.3	32.3	41.990	33.350	1400.367
A5	14	1.25	17.500	28.375	496.563
A6	11.75	1.2	14.100	15.850	223.485
A7	1.6	2.75	4.400	13.875	61.050
A8	14	1.25	17.500	10.125	177.188
A9	1.6	2.75	4.400	2.625	11.550
A10	11.75	1.25	14.688	0.625	9.180
A11	2.75	1.6	4.400	0.800	3.520
B1	2.75	1.6	4.400	49.200	216.480
B2	11.75	1.25	14.688	49.375	725.195
B3	1.25	50	62.500	25.000	1562.500
B4	1.3	48.75	63.375	24.375	1544.766
B5	10.45	1.2	12.540	15.850	198.759
B6	10.45	1.25	13.063	0.625	8.164
B7	2.75	1.6	4.400	0.800	3.520
				Total Moment:	9146.461
				Full sec area:	**375.530**
				CGy	**24.35613799**

Mechanical Properties: Centre of Gravity, X - axis

Moments about left edge as Y - axis & bottom LH corner as origin:

Part	L	B	Area	Dist of area CG from origin (X)	Moment
A1	2.75	1.6	4.400	14.375	63.250
A2	11.75	1.25	14.688	5.875	86.289
A3	1.25	50	62.500	12.375	773.438
A4	1.3	32.3	41.990	0.650	27.294
A5	14	1.25	17.500	20.000	350.000
A6	11.75	1.2	14.100	5.875	82.838
A7	1.6	2.75	4.400	0.800	3.520
A8	14	1.25	17.500	20.000	350.000
A9	1.6	2.75	4.400	0.800	3.520
A10	11.75	1.25	14.688	5.875	86.289
A11	2.75	1.6	4.400	14.375	63.250
B1	2.75	1.6	4.400	25.625	112.750
B2	11.75	1.25	14.688	34.125	501.211
B3	1.25	50	62.500	27.625	1726.563
B4	1.3	48.75	63.375	39.350	2493.806
B5	10.45	1.2	12.540	33.475	419.777
B6	10.45	1.25	13.063	33.475	437.267
B7	2.75	1.6	4.400	25.625	112.750
				Total Moment:	7630.560
				Full sec area:	**371.130**
				CGx	**20.56034274**

Derive the area moment of inertia Ixx & Iyy of the section: Divide the section into number of uniform regular areas.
Area moment of Inertia of rectangle : $bh^3/12$, where b is base & h is height.
Then summation of MOI is transferred to CG axes by parallel axis theorem : I X As^2



For I

Mechanical Properties : Area moment of Inertia, X - axis

	x	y
CG	20.56	**24.36**
	Dist from left	**Ht from bottom**

Part	b	h	I	A	y (frm CG)	+ 1 OR -1	I xcg	r=sqrt(I/A)
Full sec	40.00	50.00	416666.667	2000.000	0.644	1.000	417495.783	14.448
C1	8.50	1.60	2.901	13.600	24.840	-1.000	-8394.449	24.844
C2	10.45	32.30	29345.574	337.535	8.240	-1.000	-52263.391	12.443
C3	14.00	19.40	8518.281	271.600	14.340	-1.000	-64368.910	15.395
C4	10.45	32.30	29345.574	337.535	8.240	-1.000	-52263.391	12.443
C5	14.00	17.00	5731.833	238.000	5.110	-1.000	-11946.513	7.085
C6	1.60	8.50	81.883	13.600	16.110	-1.000	-3611.520	16.296
C7	10.15	14.00	2320.967	142.100	16.110	-1.000	-39200.478	16.609
C8	14.00	7.90	575.212	110.600	18.810	-1.000	-39707.273	18.948
C9	10.45	14.00	2389.567	146.300	16.110	-1.000	-40359.113	16.609
C10	8.50	1.60	2.901	13.6	23.56	-1.000	-7551.902	23.565
							97828.843	
			Net area	**375.530**				
			Av. R-O-G	**16.140**		Ixx=	320601.2972	

Mechanical Properties : Area Moment of Inertia, Y - axis

	x	y
CG	**20.56**	24.36
	Dist from left	Ht from bottom

Part	b	h	I	A	y (frm CG)	+ 1 OR -1	I ycg	r=sqrt(I/A)
Full sec	50.00	40.00	266666.667	2000.000	0.560	1.000	267294.635	11.561
C1	1.60	8.50	81.883	13.600	0.560	-1.000	-86.148	2.517
C2	32.30	10.45	3071.639	337.535	14.035	-1.000	-69559.697	14.356
C3	19.40	14.00	4436.133	271.600	0.560	-1.000	-4521.307	4.080
C4	32.30	10.45	3071.639	337.535	12.915	-1.000	-59371.540	13.263
C5	17.00	14.00	3887.333	238.000	0.560	-1.000	-3961.970	4.080
C6	8.50	1.60	2.901	13.600	19.760	-1.000	-5313.125	19.765
C7	14.00	10.15	1219.958	142.100	13.885	-1.000	-28615.875	14.191
C8	7.90	14.00	1806.467	110.600	0.560	-1.000	-1841.151	4.080
C9	14.00	10.45	1331.360	146.300	12.915	-1.000	-25733.794	13.263
C10	1.60	8.50	81.883	13.600	0.560	-1.000	-86.148	2.517
							68203.879	
			Net area	**375.530**				
			Av. R-O-G	**13.477**		Iyy=	226950.8094	

SECTION PROPERTIES - SE rail, 50H (R0)

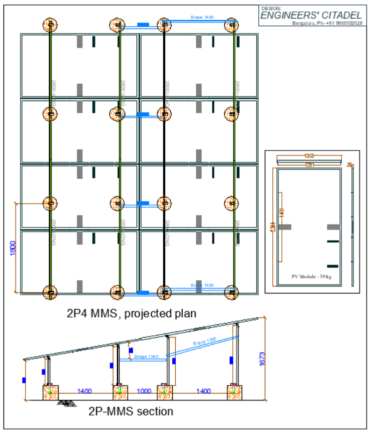
No	Notation	SE Rail sectional properties			
		inch		mm	
1	Ax	in2	0.582	mm2	375.530
2	D	in	1.97	mm	50.000
3	B	in	1.57	mm	40.000
4	t	in	0.07	mm	1.700
5	Icgx	in4	0.235	mm4	97828.843
6	Icgy	in4	0.164	mm4	68203.879
7	Ixx	in4	0.770	mm4	320601.297
8	Iyy	in4	0.545	mm4	226950.809
9	Wt	lb/ft	0.68	kg/m	1.014
10	Sx	in3	0.290	mm3	4758.133
11	Sy	in3	0.171	mm3	2800.275
12	rx	in	0.64	mm	16.140
13	ry	in	0.53	mm	13.477
14	J	in4	0.328	mm4	136407.757
15	CGx	in	0.81	mm	20.5603
16	CGy	in	0.96	mm	24.3561

Final sectional properties of the selected section, which shall be updated in STAAD library for the custom section.

LOAD CALCULATION WHEN USED AS A STRUCTURAL MEMBER

The extrusion so designed shall be used as a load bearing member in the structure. The external loads coming on the member shall be calculated from basic principles & from applicable IS codes.

In the example considered here, the member is used as load member in a Solar PV Module mounting structure.



The loads on the main members are calculated as per IS 875 (Part 3) : 2015. The load combinations are considered as per Table-4, IS-800-2007.

DESIGN LOAD CALCULATION:

Design as per IS 875 (3)		
Solar panel size:		
Length:	2384	mm
Width:	1303	mm
Thickness:	35	mm
Weight:	39.00	kg
Allowed pressure on PV Module:	2400	N/m2
Thermal expansion allowed	5	mm
Minimum ground clearance	~ 800	mm
Designed for location :	South, India.	
Tilt angle of modules :	10	Deg

Wind load (IS-875)			
Basic wind speed Vb	41.6	m/s	IS 875 (Part 3) : 2015
	150	km/hr	

Design wind speed, Vd	=Vb X K1 X K2 X K3		As per IS-875-3-2015, Clause 6.3.1, Table-1
K1	0.9	25Yrs	As per IS-875-3-2015, Clause 6.3.1, Table-1
K2	1.01	Terrain-3, Ht 20m	As per IS-875-3-2015, Clause 6.3.2, Table-2
K3	1	Slope<3°	As per IS-875-3, Clause 6.3.3
K4	1	Importance factor	As per IS-875-3, Clause 6.3.4
Vz=	37.81	m/s	
Design wind pressure :			
Pz= 0.6 X Vd^2			IS-875-3-2015, Clause 7.2
Pz	857.96	N/sqm	< allowed pressure for the Modules, hence **SAFE**.
	87.46	Kg/sqm	
Design wind pressure Pd:	Pd =PzXKdXKaXKc		IS-875-3-2015, Clause 7.2
kd	0.90	Direction	IS-875-3-2015, Clause 7.2.1
ka	1.00	Tributory	As per IS-875-3-2015, Clause 7.2.2, Table-4
kc	1.00	Combination	As per IS-875-3-2015, Clause 7.3.3.13
Reduction factor	0.80	20%	As per IS-875-3-2015, Clause 6.3 NOTE
Pd=	617.73	N/sqm	

Purlin Load calculation:

Type of building :	Freestanding Monosloped roof type of structure. IS-875-3-2015, Table-8		
Roof angle	10	Deg	Positive
Pr. coefficient:			
Pushing :	0.5		For 10 deg tilt (+)
Lifting :	0.9		For 10 deg tilt & Phi=0 (-)
Load on Purlins :			
Length of purlin supporting module	2.646	m	
Length of Table	13.03	m	1 X 10 MMS- South tilt
Width of Table	2.384	m	1 X 10 MMS- South tilt
Tot Modules self wt (Dn)	382.59	N	Wt of one module
Modules wt per m of purlin: (Dn)	144.59	N/m	Purlin length taken.
Pushing wind load (Dn):			
Tot wind down pressure:	**308.86**	**N/m2**	
Tot wind down load on a module:	959.44	N	For one module area.

Down wind load per m of purlin:	362.60	N/m	Center of pressure at 0.5w.
Lead Purlin-1, UDL:	543.90	N/m	Center of pressure at 0.3w, Note-1, Table-8, IS-875Part-3, 2015
Lead Purlin-2, UDL:	253.82	N/m	--------- "" "" ---------
Lead Purlin-3, UDL:	145.04	N/m	--------- "" "" ---------
Lead Purlin-4, UDL:	72.52	N/m	--------- "" "" ---------
Lifting wind load (Up) :			
Tot up wind pressure:	**555.96**	**N/m2**	
Tot up wind load on a module:	1727.00	N	For one module area.
Up wind load per m of purlin:	652.68	N/m	Center of pressure at 0.5w.
Lead Purlin-1, UDL:	979.02	N/m	Center of pressure at 0.3w.
Lead Purlin-2, UDL:	456.88	N/m	--------- "" "" ---------
Lead Purlin-3, UDL:	261.07	N/m	--------- "" "" ---------
Lead Purlin-4, UDL:	130.54	N/m	--------- "" "" ---------

Wind Load - Lateral

Wind load on members in lateral direction :			As per IS-875-3, Clause 7.4.3.2 (b), Table-29
Force co-efficient, NORMAL, Cfn=	2.05		Considered for C-section.
Member wind load in Z direction for Post =	63.32	N/m	F = Cf * k * P * area Width of Post=50mm

Purlin Design loads:

Module Dead Load : Weight per meter on Purlin	0.0001446	kN/m	UDL
Down wind load: kN/m	0.000544	0.000254	0.000145
Up wind load : kN/m	0.000979	0.000457	0.000261
Lat wind load per m of post:	0.000063	kN/m	UDL

Basic & Combination load cases:

Primary load No	**Name**
1	Dead Load
2	Wind load - Dn
3	Wind load - Up
4	Wind load - Lat

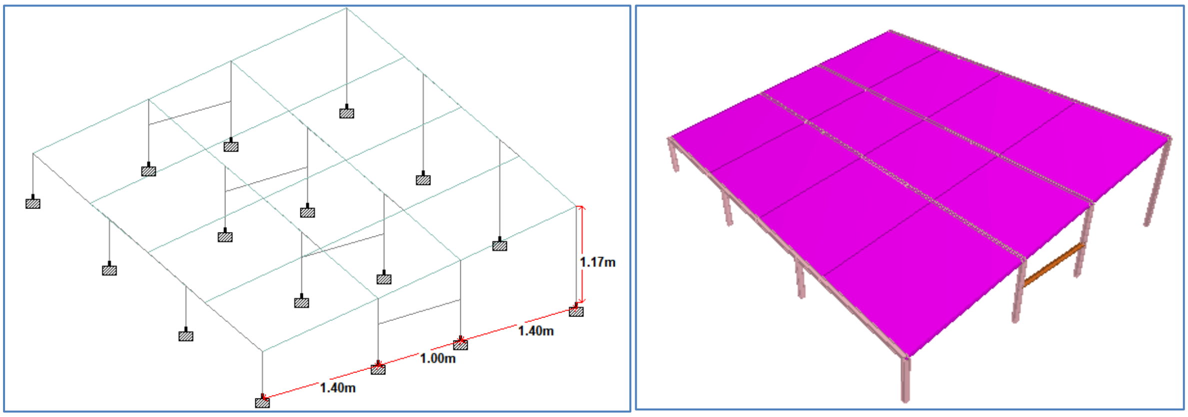
Table-4, IS-800-2007	**L.S. of Strength**	**L.S. of Service**
DL + LL	1.5 + 1.05	1 + 1
DL + LL + WL	1.2 + 1.05 + 0.6	1 + 0.8 + 0.8
DL + WL	1.5 + 1.5	1 + 1

STRUCTURAL ANALYSIS AND STABILITY CHECK

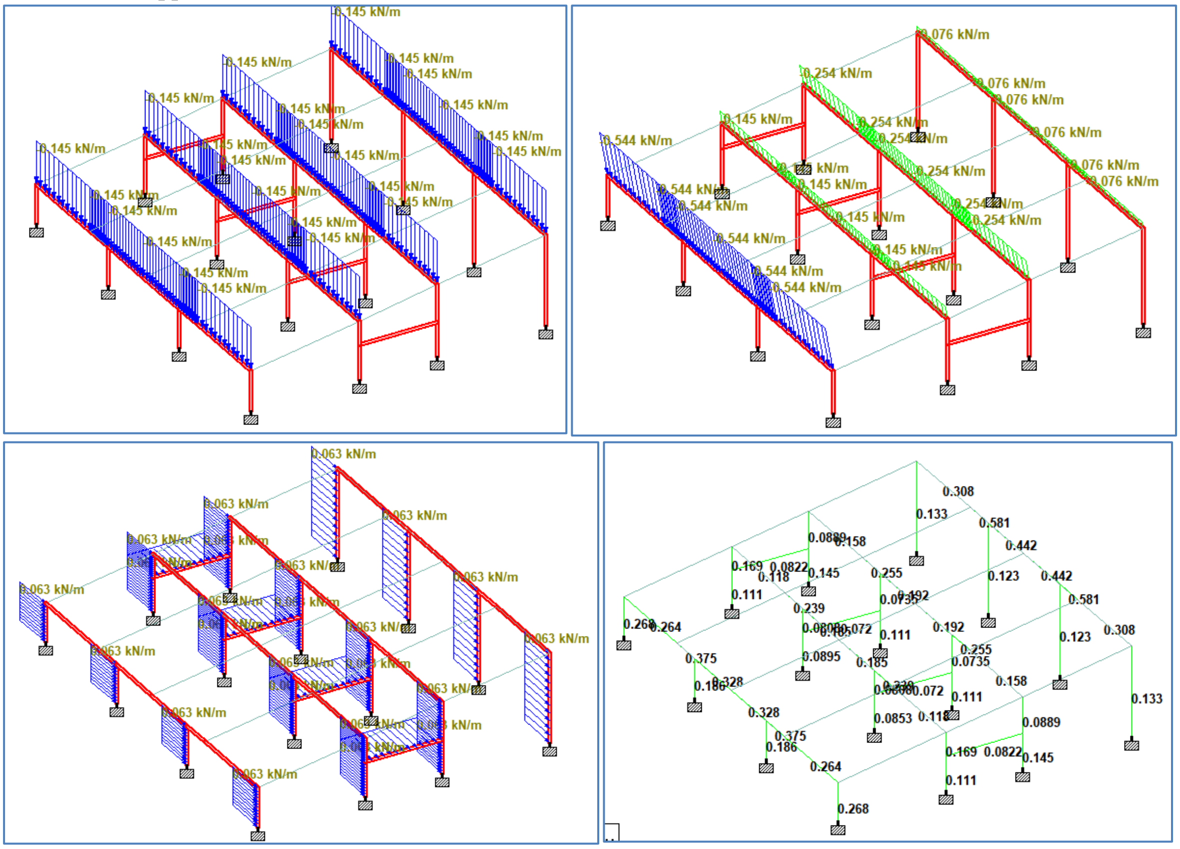
The structure shall then be analyzed by applying the loads to check the stability for permissible deflection of members & for stress levels.This can be done either from basic principles manually or by using any suitable computer based analysis tools.

Here the analysis is done using the tool Staad-Pro.

Staad Model:



Purlin Loads applied:



Summary of Analysis results from STAAD output:

Deflection :

No	Member	Sample length (mm)	Allowed deflection (mm)	Actual max displacement (STAAD) (mm)
1	Purlin Rail	1600	8.0	1.9
2	Post	350	1.1	1.416
				SAFE

Note :

Maximum deflection allowed for PV modules is L/100.
As per IS 800:2007, following is considered for design check :

1 For cantilever = L / 100
2 For simply supported = L / 200 (IS : 8147 - 1976, CL 8.3.1)
3 For column = L /240 (lateral deflection for column as per, IS-800-2007, table-6)
For Alu column = L / 325 (IS : 8147 - 1976 , CL-8.2.9)
All deflections are within allowable limits, hence **SAFE.**

Utilization Ratio:

No	Member	Max allowable ratio	Actual ratio (STAAD)	Conclusion
1	Purlin Rail	1	0.594 (Member 405)	**SAFE**
2	Post	1	0.288 (Member 365)	**SAFE**

If the structure results show failure of the member under the maximum load combination, the section has to be redesigned, going back to design stage & repeat the subsequent steps.

EXTRUSION DIE DESIGN

The design of an extrusion die for aluminum alloys is a critical process that directly impacts the quality, integrity, and cost of the final product. Here are some of the key design parameters to consider:

Profile Shape and Complexity: The shape of the final extruded profile is the most fundamental parameter. Dies are designed differently for solid, semi-hollow, and hollow profiles. Hollow dies, for instance, are more complex and expensive to manufacture, requiring multiple components like a mandrel and a die cap to create internal voids. The section finalized here requires 4 mandrels to achieve the required section.

Die Material and Strength: The die must be able to withstand the high pressures (up to 15,000 tons) and temperatures of the extrusion process. H13 steel is a common choice due to its strength, wear resistance, and toughness. The overall dimensions and design of the die (e.g., the use of backers and bolsters) are critical for ensuring it can handle the applied forces without deforming or fracturing. The design of the die's "tool stack" is also important for providing support.

Metal Flow Control: Achieving a uniform flow of the aluminum alloy through the die is paramount for a high-quality product. Key design features for controlling flow include:

Bearing Length: This is the distance the aluminum travels within the die. Longer bearing lengths increase resistance and slow down the flow, while shorter ones do the opposite. Designers use variable bearing lengths to ensure all parts of a complex profile exit the die at the same speed.

Feeder Plates/Channels: These are used to distribute the molten aluminum evenly and minimize turbulence.

Die Angle: The angle of the die entry can be adjusted to control the flow and pressure, influencing the mechanical properties and surface finish of the extruded product.

Dimensional Tolerances and Wall Thickness: The required tolerances for the final product directly influence the precision needed in the die's geometry. Maintaining a uniform or low variation in wall thickness is a key consideration. Large differences in wall thickness can lead to dimensional control problems, surface defects and distortion. A common guideline is to keep the ratio of adjacent wall thicknesses less than 2:1.

Extrusion Ratio: The extrusion ratio is the ratio of the cross-sectional area of the billet to the cross-sectional area of the final profile. This ratio indicates the difficulty of the extrusion and affects the mechanical properties of the product. It is generally recommended to be between 10 and 150. A higher ratio typically leads to better mechanical properties but requires higher pressure.

Tongue Ratio: For semi-hollow and hollow profiles, the tongue ratio is an important parameter. It is defined as the area of the void divided by the square of the gap width. A higher tongue ratio indicates a more difficult extrusion and a greater risk of the die "tongue" (the part forming the void) breaking. Rounded corners instead of sharp ones can help strengthen the die tongue.

Surface Finish: The quality of the die's surface finish directly affects the surface of the extruded profile. A smooth, well-polished die is essential for producing a high-quality surface finish on the final product. Die lubricants and proper process parameters (temperature and speed) also play a role.

VI. CONCLUSION

This paper attempts to provide a comprehensive overview of the design principles for aluminium alloy extrusion, a manufacturing process fundamental to modern industry.

This paper demonstrates that achieving a successful extrusion design is a holistic endeavor, requiring the integration of several key elements of engineering.

In conclusion, successful aluminium extrusion is an integrated engineering challenge that demands a deep understanding of final application, metallurgy, process dynamics, assembly methods, post process requirements and die design. The harmonious optimization of these factors is crucial for producing cost-effective, high-quality and complex profiles that meet the stringent demands of specific industrial applications.

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REFERENCES

[1]. IS-875 (2015) Code of practice for Design loads for buildings & structures.
[2]. IS-800 (2007) Code of practice for General construction in Steel
[3]. IS-8147 (1976) Code of practice for use of Aluminium alloys in structures
[4]. IS 733 (1983) Wrought Aluminium & its Alloy Bars, Rods, Sections for General Engg Purposes
[5]. IS 6051:1970 - Code for Designation of Aluminium and its Alloys.