INDIAN WELDING JOURNAL Volume 53 No. 4, October, 2020

An Approach to Best Welding Practice Part – XX.

S. K. Gupta, B.E., C.E., FIE., FIIW., MISNT., MAE., MITD.
E-mail : skg1938@gmail.com

DOI No.10.22486/iwj.v53i4.203668

ORCID: Samir Kumar Gupta: https://orcid.org/0000-0002-1504-8301

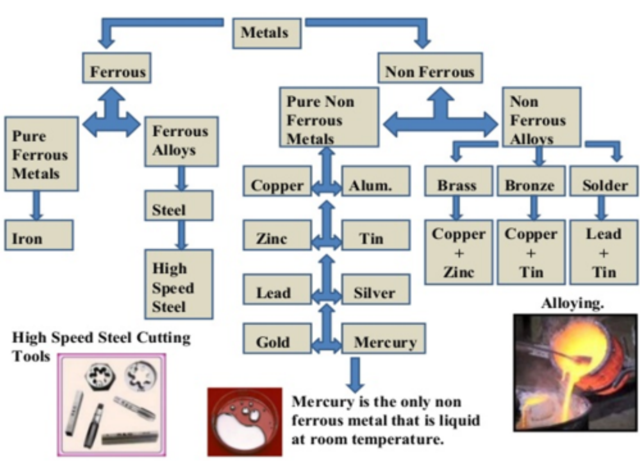
"AN APPROACH TO BEST WELDING PRACTICE. **Part – XX."** is the Twentieth Detail Part of **"AN APPROACH TO BEST WELDING PRACTICE"** which is a General and Overall approach to the subject matter.

AN APPROACH TO BEST WELDING PRACTICE. Part – XX, Section II is particularly focused on the Generation and Computer based Storage of Welding Data on Materials for Fabrication. It is required as a Working Guideline for Planning Engineers, Welding Coordinators and Quality Managers working in an Engineering Fabrication Plant using welding as the main manufacturing process.

In fact, details of materials structures, strengths, property changes with temperature, density, thermal conductivity are some of the essential data to be generated, stored and retrieved as and when required in welded fabrication work. It is a lengthy process to develop and as each and every step is connected with each other for cross references, none can be eliminated.

The essential and vital information are provided below along with some tables and charts. But bulk information sheets will follow later.

MATERIALS FOR FABRICATION



- ❖ Carbon in same range as mild steels 0.15 – 0.25%
- ❖ Small amounts of alloying elements Mo, Cr, Cu, Ni etc added eg. weathering steels to IS: 11587
- ❖ Structure accicular ferrite and bainite or ferrite and tempered martensite
- ❖ Sronger and tougher than pearlitic steels with higher strength
- ❖ Hardenability is increased which affects weldability

YS	400-700 MPa
UTS	500-800 MPa
Elongation	18-25%

Micro – alloyed HSLA steels

- ❖ Fine dispersion of alloy carbides results in strengthening by precipitation hardening
- ❖ Small amounts of carbide forming elements eg. Nb, V, Ti etc added Total amount 0.20% max as such called Micro-alloyed steels
- ❖ Controlled rolling at low finish roll temperatures results in very fine grain size ASTM 12 – 14. Also improves strength.
- ❖ Range of medium and high tensile steel developed to give improved strength and toughness without impairing weldability. Covered by IS:8500 - 1991
- ❖ Gives comparitively lower elongation but better toughness than low alloy HSLA steels
- ❖ Properties :

UTS	600 – 650 MPa
YS	400 – 500 MPa
Elongation	20 – 22 %

Effect of alloying elements

SULPHUR

Sulphur can be added up to ~ 0.35 % by weight. It is used in free-cutting steels in combination with manganese additions, to give manganese sulphide inclusions which deform plastically during rolling and cutting; these elongated inclusions promote chip formation and breakup during subsequent machining. They also reduce cutting temperatures and tool wear.

MANGANESE

Manganese is used to harden steels and increase its toughness and strength. High manganese content coupled with increased carbon content lowers the ductility and weldability. Consideration of preheat and or postheat techniques usually apply.

MOLYBDENUM

May be used in conjunction with other elements to aid in hardening and provide steel with good strength at elevated temperatures. Preheating may be required for welding and they are often heat treated after welding.

NICKEL

Nickel may be used to Increase toughness and impact strength and improve corrosion resistance. Good strength and ductility may be obtained even with lower carbon content. Depending on the amount added special procedures may be necessary when welding.

CHROMIUM

Chromium helps improve the hardenability of steels and improves wear resistance, heat resistance, and corrosion resistance. Depending on the amount added special procedures may be necessary when welding. Chromium and Chromium Nickel are used in the production of Stainless Steel.

What are Stainless Steels

- ☆ Steels containing 11 - 30% Chromium
- ☆ The chromium oxide forms a passive layer on the surface which is adherent and regenerative.
- ☆ This prevents corrosive attack and gives the steel its " stainless" property.
- ☆ Minimum 11% Cr needed to protect against atmospheric corrosion.
- ☆ Elements like Ni, Mo, Cu, Nb, Ti etc added to improve mechanical properties and corrosion resistance
- ☆ Do not resist corrosion in strongly reducing media.

Types of stainless steels

- ☆ Martensitic
- ☆ Ferritic
- ☆ Austenitic
- ☆ Duplex
- ☆ (Austenite +Ferrite)

Martensitic stainless steels

- ☆ Cr 12 –18%
- ☆ C 0.1 – 1.2%
- ☆ AISI 410, 420, 440 grades
- ☆ Martensitic structure - higher carbon grades used in tempered condition.

  Used for cutlery, surgical instruments, steam, gas & hydel turbine blades, ball bearings and races

Ferritic stainless steels

- ☆ Cr 11 – 30%
- ☆ C 0.02 – 0.2%
- ☆ AISI 405, 430, 446 grades
- ☆ Ferritic structure -higher ductility and resistance to SCC & pitting corrosion.
- ☆ Used as thin sheet for decorative applications, oxidising corrosive media, heat resisting applications.

Austenitic stainless steels

- ☆ Cr 16 – 26%
- ☆ Ni 6 – 26%
- ☆ AISI 304, 310, 316, 321 & 347 grades
- ☆ Austenitic structure gives good weldability with excellent ductility and toughness down to cryogenic temperatures.
- ☆ Nickel improves general corrosion resistance
- ☆ Widely used for chemical, petrochemical plant, food processing and dairy equipment. Also used for cryogenic plant
- ☆ Physical properties of austenitic stainless steels
- ☆ Has high coefficient of linear expansion, twice that of carbon steels
- ☆ Has poor thermal conductivity, half that of carbon steels
- ☆ Results in much higher distortion after welding
- ☆ Steps to prevent distortion
  - closer tacking
  - greater use of jigs and fixtures
  - use of balanced and skip welding techniques

Limitations of Standard Stainless Steels

- ☆ Low proof stress – 35% of UTS
- ☆ Sensitive to stress corrosion in acidic Cl or F ion media above 70 C and also hot caustic
- ☆ Sensitive to pitting corrosion in more aggressive acid chloride media Preferential attack on the ferrite phase in weak reducing media (urea carbamate)
- ☆ Inadequate corrosion resistance in stronger reducing media such as hot phosphoric acid or sulphuric acid

Steel makers have developed new grades of stainless steel to overcome these limitations and meet the requirements of higher operating pressures / temperatures or liquor concentrations demanded by modern chemical and petro-chemical plant

Duplex stainless steels

- ✰ Half the nickel content of austenitic steels
- ✰ Cr 18 – 28% Ni 4.5 – 9.0 %
- ✰ 50% austenite + 50% ferrite structure
- ✰ Almost twice the strength of austenitic steels
- ✰ Excellent pitting + SCC resistance
- ✰ Used for plant and piping in oil and gas production, corrosive applications to resist chloride ion media. Higher strength structurals.

About Duplex Stainless Steels

Corrosion Resistance

- They are extremely corrosion resistant having high resistance to intergranular corrosion. Even in chloride and sulphide environments, they exhibit very high resistance to stress corrosion cracking.
- The super duplex grades are even more resistant to corrosion

Heat Resistance

- High chromium content gives protection against corrosion, but causes embrittlement at temperatures over about 300°C.
- At low temperatures they have better ductility than ferritic and martensitic grades. Duplex grades can readily be used down to at least -50°C.

Heat Treatment

- They can not be hardened by heat treatment. Can however be work hardened.
- Solution treatment or annealing can be done by rapid cooling after heating to around 1100°C.

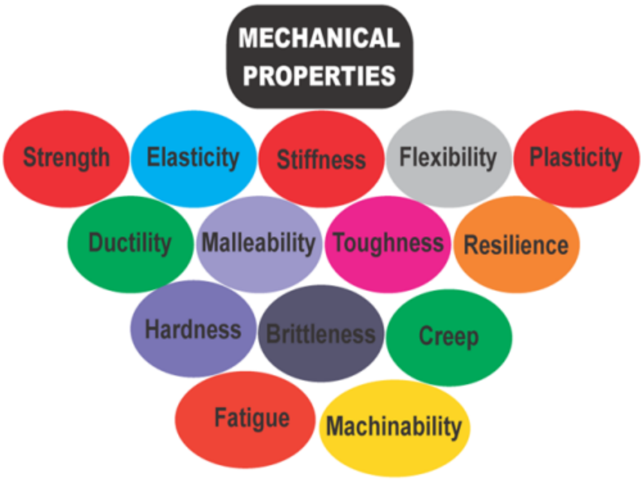
All composite and fabricated structures work under different environmental and loading conditions such as :

- ✰ Static or Dynamic loading
- ✰ Concentrated or Distributed loading
- ✰ Tension, Compression or Torsional loading
- ✰ Combination of above loadings
- ✰ At normal temperature
- ✰ At sub-zero temperature
- ✰ At elevated temperature

1. Mechanical Properties of Materials

a. ultimate tensile strength
b. yield strength
c. ductility
d. toughness (Kjc, CVN)
e. hardness
f. creep

1. Mechanical Properties of Materials



g. fatigue
h. stress rupture (most lacking in HAZ data)

2. Physical Properties of Material—

a. modulus,
b. conductivity,
c. density
d. formability
e. machinability
f. hardenability
g. wear and abrasion characteristics

3. Corrosion rates – Electrode potential

The driving force for the flow of current and thus the corrosion is the difference in electrode potential. The electrode potential of a metal is an indication of the tendency of the metal to dissolve and corrode in a certain electrolyte

The electrode potentials of different metals can be specified in relation to one another in galvanic series for different electrolytes.

Considering the steel-copper example, it will be noted from theGalvanic Table that the copper has a higher potential (is nobler) than plain carbon steel. The steel will be the anode and corrode, whereas the copper will be the cathode and not corrode.

4. Additional metallurgical characteristics

a. cleanliness
b. composition
c. prior history, including thermal treatment or deformation

5. Chemical properties

6. Weldability

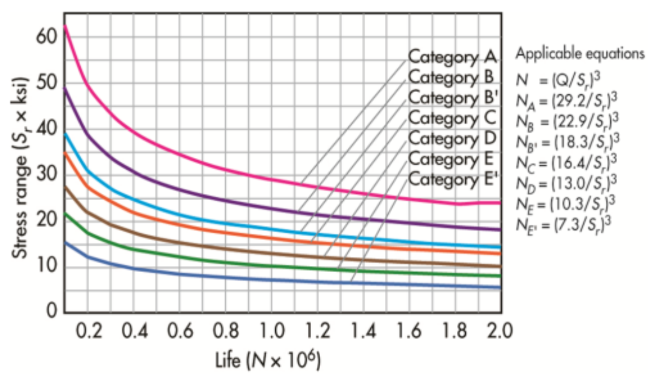
Fracture is classified based on several characteristic features:

Characteristic	Terms used	Terms used
Strain to fracture	Ductile	Brittle
Crystallographic mode	Shear	Cleavage
Appearance	Fibrous and gray	Granular and bright
Crack propagation	Along grain boundaries	Through grains

Fatigue Category Coefficients

	TRB coefficient	AWS coefficient	Alternative coefficient
Category	A x 10^8	C_f x 10^8	Q
A	250	250	29.2
B	119	120	22.9
B'	61.1	61	18.3
C	44.5	44	16.4
D	21.8	22	13.0
E	10.7	11	10.3
E'	3.91	3.9	7.3

Stress Range Curves

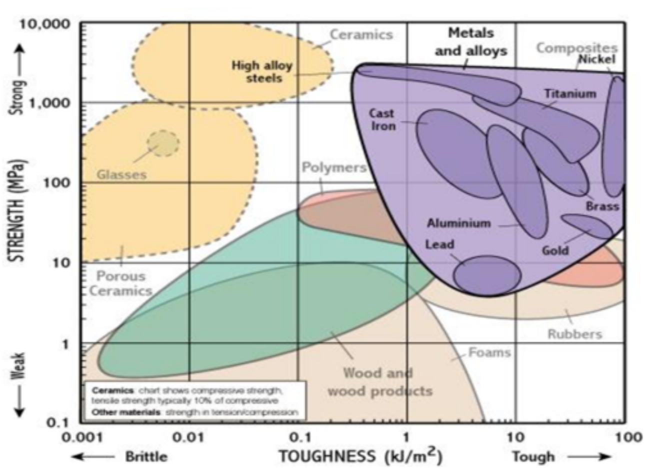


Strength and stiffness.

The words 'stiffness' and 'strength' both imply a sense of resistance and are both determined by geometry and material properties. However, a strong object may not necessarily be stiff, and vice versa!

Strength ≠ Stiffness

- Strength [N/m^2] is the maximum stress that the material can resist before deformation or fracture.
- Stiffness [N/m] is the rigidity or resistance to bending.



Aluminium Alloys, Prpoperties And Uses

Aluminium is not just one material, but it gives rise to a family of different groups of alloys whose mechanical properties widely vary from one group to another and also within each group itself. From the point of view of the technological use, the aluminium alloys can be grouped into eight series, according to the American Association classification, the first of the four digits characterizing the main alloying element and the other three the secondary ones.

Copper-Base Alloys

Copper and copper-base alloys have specific properties which make them widely used. Their high electrical conductivity makes them widely used in the electrical industries and corrosion resistance of certain alloys makes them very useful in the process industries. Copper alloys are also widely used for friction or bearing applications.

Copper shares some of the characteristics of aluminum. Attention should be given to its properties that make the welding of copper and copper alloys different from the welding of carbon steels.

Copper alloys possess properties that require special attention when welding. These are:

1. High thermal conductivity.
2. High thermal expansion coefficient.

Series	Alloy	Properties	Uses
1XXX	Al	Its elastic limit is very low (f0.2@30 Nmm-2), but its ductility is excellent, being the ultimate elongation et@30 to 40 percent. If the material is cold-worked, the strength can increase up to f0.2@100 Nmm-2, whereas the ductility is drastically reduced (et@3 to 4 percent).	Not used much in Industries electrical conductors.
2XXX	Cu	. When submitted to heat-treatment, elastic limit f0.2 can increase up to 300 Nmm-2, with a sufficient ductility, being et@10 percent. the corrosion resistance of these alloys is not very high and poor weldability	Basically, they are used in aeronautical industry with riveted connections.
3XXX	Man	These alloys cannot be heat-treated and they have a slightly higher strength than pure aluminium by keeping a very high ductility, which allows very hard cold-forming processes for increasing strength. They are corrosion resistant.	Specific applications are panels and trapezoidal sheeting for roofing systems.
4XXX	Si	The properties of these alloys are similar to those of the 3000 series	Not often used, except for welding wires.
5XXX	Mag	Even though these alloys cannot be heat-treated, their mechanical properties could be higher than those corresponding to the 1000, 3000 e 4000 series. The strength can be increased when they are cold worked, being the elastic limit f0.2 up to 200 Nmm-2 and the ductility still quite high (et up to 10 percent). The corrosion resistance is also high, especially in marine environment, when the amount of Mg is less than 6 percent. These alloys are often used in welded structures, since their strength is not drastically reduced in the heat-affected zone.	Used especially in marine environment, when the amount of Mg is less than 6 percent. These alloys are often used in welded structures, since their strength is not drastically reduced in the heat-affected zone.
6XXX	Mag-Si	By means heat-treatment the strength of these alloys is increased up to f0.2 @ 250 Nmm-2, with a quite good ductility, being et up to 12 percent. These alloys are corrosion resistant.	These are particularly suitable for extrusion, but also rolled sections as well as tubes can be produced. These alloys are used either in welded structures and in bolted or riveted connections
7XXX	Zinc	- AlZnMg alloys reach a remarkable strength, being the elastic limit f0.2 greater than 250 Nmm-2, with a quite good ductility (et @ 10 percent). They are also corrosion resistant. - AlZnMgCu alloys are the highest resistance alloys after heat-treatment, reaching f0.2 @ 500 Nmm-2; conversely, they have low weldability and are not corrosion resistant,	These alloys are generally used in structural applications, because they are particularly suitable in welded structures owing to their self-tempering behaviour, which allows to recover the initial strength in the heat-affected zone.
8XXX	Al- Fe- Si-		This series is preferably used as material for packaging but, due to its advantages in fabrication, it finds more and more application in building industry for facades.

3. Relatively low melting point.
4. It is hot short, i.e., brittle at elevated temperatures.
5. The molten metal is very fluid.
6. It has high electrical conductivity.
7. It owes much of its strength to cold working.

Magnesium - Base Alloys

Magnesium is the lightest structural metal. It is approximately two-thirds as heavy as aluminum and one-fourth as heavy as steel. Magnesium alloys containing small amounts of aluminum, manganese, zinc, zirconium, etc., have strengths equaling that of mild steels. They can be rolled into plate, shapes, and strip.

Magnesium can be cast, forged, fabricated, and machined. As a structural metal it is used in aircraft. It is used by the materials-moving industry for parts of machinery and for hand-power tools due to its strength to weight ratio.

Magnesium can be welded by many of the arc and resistance welding processes, as well as by the oxy-fuel gas welding process, and it can be brazed. Magnesium possesses properties that make welding it different than the welding of steels. Many of these are the same as for aluminum. These are:

1. Magnesium oxide surface coating
2. High thermal conductivity
3. Relatively high thermal expansion coefficient
4. Relatively low melting temperature
5. The absence of color change as temperature approaches the melting point.

Nickel - Base Alloys

Nickel and the high-nickel alloys are commonly used when corrosion resistance is required. They are used in the chemical industry and the food industry. Nickel and nickel alloys are also widely used as filler metals for joining dissimilar materials and cast iron.

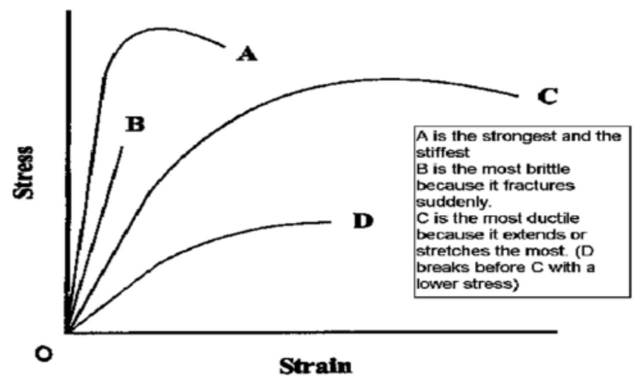
When welding, the nickel alloys can be treated much in the same manner as austenitic stainless steels with a few exceptions. These exceptions are:

1. The nickel alloys will acquire a surface oxide coating which melts at a temperature approximately 538oC above the meting point of the base metal.
2. The nickel alloys are susceptible to embrittlement at welding temperatures by lead, sulphur, phosphorus, and some low temperature metals and alloys.
3. Weld penetration is less than expected with other metals.

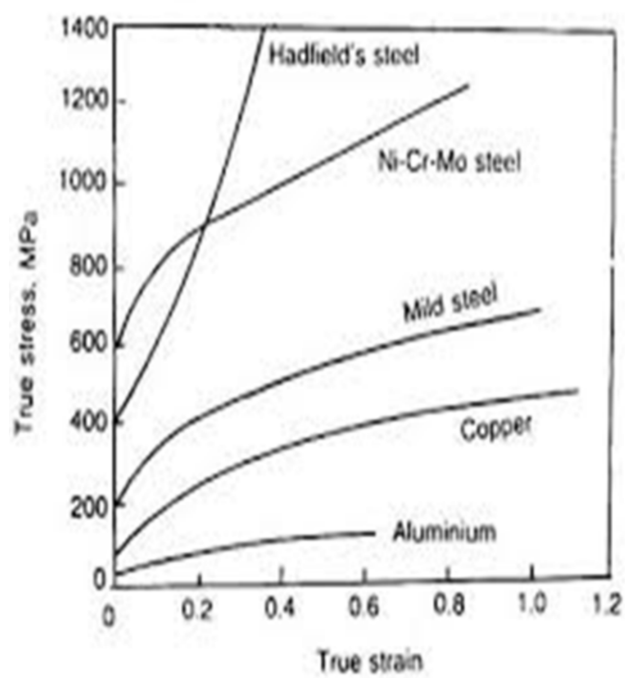
END OF PART – II – MATERIALS .

The subject being exhaustive the Basic Concept of only the essential items have been discussed and that too in a brief manner. Every Item will have to be elaborated with Diagrams, Charts and Tables. In this part only few Charts, Tables and Diagrams are given in the text. A few are provided in the annexure. Other topics and items will be separately illustrated in the following Parts.

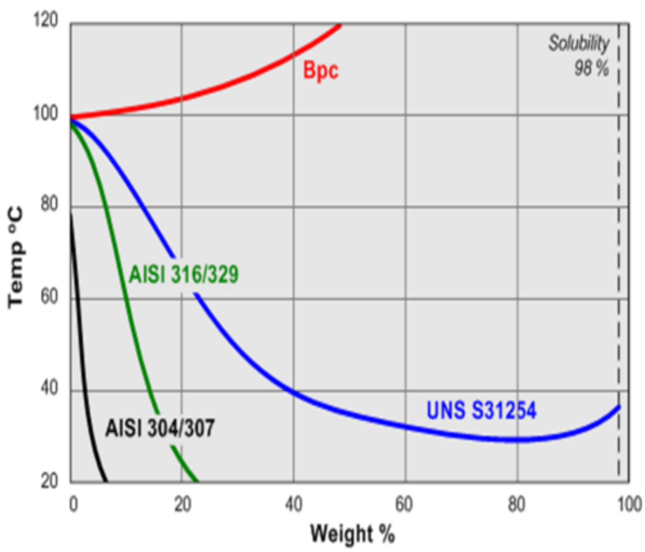
ANNEXURE – I



A graph showing stress strain of four materials

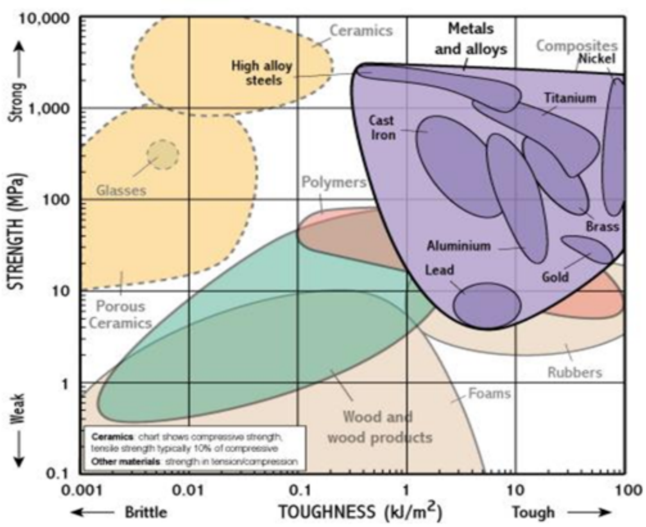


True stress-strain curve of some metals and alloys



ANNEXURE – II

Strength – Toughness Diagram



Corrosion

Metal	Electrode potential, volt
Gold	+0.42
Silver	+0.19
Stainless steel (AISI 304), passive state	+0.09
Copper	+0.02
Tin	-0.26
Stainless steel (AISI 304), active state	-0.29
Lead	-0.31
Steel	-0.46
Cadmium	-0.49
Aluminium	-0.51
Galvanized steel	-0.81
Zinc	-0.86
Magnesium	-1.36

ANNEXURE – III

Typical Mechanical Properties of Selected Carbon and Alloy Steels (Quenched and Tempered)

AISI No.*	Tempering Temperature, Deg. F	Strength		Hardness Bhn
		Tensile	Yield	
		1000 lb/in²		
4042	400	261	241	516
	600	234	211	455
	800	187	170	380
	1000	143	128	300
	1200	115	100	238
4130†	400	236	212	462
	600	217	200	435
	800	186	173	380
	1000	150	132	315
	1200	118	102	245
4140	400	257	238	310
	600	225	208	445
	800	181	165	370
	1000	138	121	285
	1200	110	95	230

Mechanical Properties	Symbol	Steel
Young's modulus (GPa)	E	207.0
Shear modulus (GPa)	G	80.0
Poisson's ratio	V	0.3
Density (Kg/m3)	ρ	7600
Yield strength (MPa)	S_y	370
Shear strength (MPa)	S_s	370

Physical and Mechanical Properties	301L stainless Steel Sheet	304 stainless Steel mesh film
Density, kg/m3	7880-7960	7850-8060
Thickness, mm	0.05	0.043
Young's module, GPa	200-210	190-203
Yield strength, MPa	179-207	205-310
Ultimate Tensile Strength, MPa	503-556	510-620
Elongation, % strain	30-40	45-60
Compression strength, MPa	159-200	205-310
Shear modulus, GPa	77- 80.9	74-81
Poisson's ratio	0.27-0.28	0.265-0.275
Hardness, Vickers (HV)	215-240	170-210

Standard Properties of the 356 Al Matrix Alloy

Property	Values
Density	2670 kg/m^3
Melting Point	615°C (liquidus)
Elastic Modulus	71 GPa
Tensile Strength (T6)	250-280 MPa
Percent Elongation	5%
Hardness (T6)	90 BHN

ANNEXURE – IV

Physical Properties Of Aluminium

Property	Value
Melting Point	655 Degree centigrade
Density	2.70 gm/ cm3
Thermal Expansion	23.5 x 10^-6/K
Modulus of Elasticity	69.5 GPa
Thermal Conductivity	201 W/m.K
Electrical Resistivity	0.033 x 10^-6 Ohm.m

STEELS

TRADE NAME	% C MAX	% MN MAX	% Si MAX	% OTHER ALLOYS	YS MPa	UTS MPa
IS 2062A	0.23	1.50	0.10	-	250	410
IS2062(Cu)	0.20	1.50	0.10	Cu-0.35	250	410
IRSM41-97	0.10	0.45	0.72	Cu-0.60	340	480
SAILMA	0.25	1.50	0.50	Nb+V+Ti 0.20	410	600
HY - 80	0.18	0.40	0.38	Ni-3.5Cr-1.8. Cu .25 .Mo-0.6	710	890
HSLA-80	0.06	0.70	0.40	Ni-3.5.Cr 0.90 Cu-1.30	710	800
HSLA-100	0.06	1.15	0.40	Ni-3.65.Cr-0.75 Mo-0.65.Cu-1.75	890	1150

ANNEXURE – V

IS : 2062 - Specification of Steel for General Structural Purposes

IS : 2062 - Specification of Steel for General Structural Purposes

CHEMICAL COMPOSITION						
Grade	C% Max.	Mn% Max.	S% Max.	P% Max.	Si% Max.	C.E.% Max.
A	0.23	1.50	0.050	0.050	0.40	0.42
B	0.22	1.50	0.045	0.045		0.41
C	0.20	1.50	0.040	0.040	0.40	0.39

MECHANICAL PROPORTIES						
Grade	UTS (MPa) Min.	Y.S. (MPa) Min.			El.% Min. 5.65 Sqrt(So)	Bend Test
A	410	250	240	230	23	3T
B	410	250	240	230	23	2T & 3T *
C	410	250	240	230	23	2T

MATERIAL : IRS : M44	
ELEMENT	PERCENTAGE
CARBON	0.03 MAX
SILICON	1.00 MAX
MANGANESE	0.8 - 1.5
CHROMIUM	10.8 - 12.5
NICKEL	1.5 MAX
PHOSPHOROUS	0.03 MAX
SULPHUR	0.03 MAX
TITANIUM	0.75 MAX

U.T.S. : 50 KG / mm ELONGATION : 25 %

ANNEXURE – VI

Properties of typical Micro-alloyed steels

Grade / Trade name	% C	% Mn	% Si	% MA	YS MPa	UTS MPa
ASTM A633 Gr C	0.20	1.50	0.50	0.05 Nb	350 min	600 min
SAILMA 410	0.25	1.50	0.50	Nb+V+Ti =0.20	410 min	540 - 660
SAILMA 450	0.25	1.50	0.50	Nb+V+Ti =0.20	450 min	570 - 720
SAILMA 450HI	0.20	1.50	0.50	Nb+V+Ti =0.20	450 min	570 - 720 CVN =19.6J Min at - 20C
TISTEN 60	0.20	1.80	0.50	0.20	440 min	590 min

Composition Of Two Typical Duplex Steels

Elements (%)	2205	UR52N + (Super Duplex)
C	0.03 Max	0.03 max
Mn	2.0	1.50
Si	1.0	0.80
S	0.03	0.035
P	0.02	0.02
Cr	21-23	24-26
Mo	2.5-3.5	3.0-5.0
Ni	4.5-6.5	5.5-8.00
N	0.08-0.2	0.2-0.35
Cu		0.5 - 3.0