30 Properties and ratings of current-carrying conductors

Contents

30.1 Properties for aluminium and copper conductors

In Table 30.1 we provide the general properties of aluminium and copper conductors. The table also makes a general comparison between the two widely used metals for the purpose of carrying current.

30.1.1 Important definitions of properties of a metal

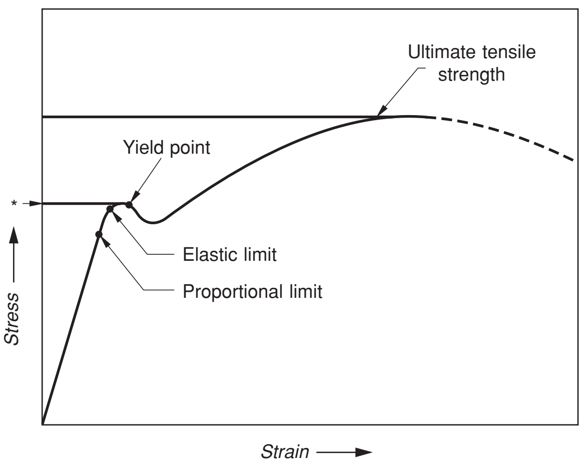
For ease of application of the above table we give below important definitions of the mechanical and electrical properties of a metal.

30.1.2 Physical and mechanical properties

1 **Specific heat** (This is a physical property) The specific heat of a substance is the heat required to raise the temperature of its unit mass by 1°C.

2 **Stresses**
This is the force per unit area expressed in kgf/mm^2 and is represented in a number of ways, depending upon the type of force applied, e.g.

- **Tensile stress:** the force that will stretch or lengthen the material and act at right angles to the area subjected to such a force.
- **Ultimate tensile strength:** the maximum stress value as obtained on a stress–strain curve (Figure 30.1).
- **Compressive stress:** the force that will compress or shorten the material and act at right angles to the area subjected to such a force.
- **Shearing stress:** the force that will shear the material and act in the plane of the area and at right angles to the tensile or compressive stress.
- **Modulus of elasticity (*E*):** the ratio of the unit stress to the unit strain within the proportional limits of a material in tension or compression.
  – **Proportional limit:** the point on the stress–strain curve at which will commence the deviation in the stress–strain relationship from a straight line to a parabolic curve (Figure 30.1).
- **Elastic limit:** the maximum stress a test specimen may be subjected to and which may return to its original length when the stress is released.
  – **Yield point:** a point on the stress–strain curve that defines the mechanical strength of a material under different stress conditions at which a sudden increase in strain occurs without a corresponding increase in the stress (Figure 30.1).
  – **Yield strength or tensileproof stress:** the maximum stress that can be applied without permanent deformation of the test specimen. For the materials that have an elastic limit (some materials may not have an elastic region) this may be expressed as the value of the stress on the stress–strain curve corresponding to a definite amount of permanent set (elongation) of, say, 0.1% or 0.2% of the test specimen.



* Tensileproof strength = 0.6 to 0.8 of ultimate tensile strength

Figure 30.1 Stress–strain curve

30.1.3 Electrical properties

Resistivity of metal of a current-carrying conductor

A metal being used for the purpose of current carrying must be checked for its conductivity. This is proportional to its current-carrying capacity. This will ascertain the correctness of size and grade of the metal chosen for a particular duty. It is necessary to avoid over-heating of the conductor during continuous operation beyond the limits in Table 28.2. The electrical conductivity of a metal is reciprocal to its resistivity. The resistivity may be expressed in terms of the following units:

- Volume resistivity or specific resistance: this is the resistance of a conductor of unit length and unit cross-sectional area, i.e.

  $$\frac{\Omega \cdot \text{m}^2}{\text{m}} \quad \text{or} \quad \Omega \cdot \text{m (or } \mu \cdot \Omega \cdot \text{m)}$$

  and $1\mu \cdot \Omega \cdot \text{cm} = 10^2 \ \dfrac{\Omega \cdot \text{mm}^2}{\text{m}}$

- Mass resistivity: this is the resistance of a conductor of unit length and unit mass; i.e. $\Omega \cdot$ gm/m^2 which is also equal to the volume resistivity multiplied by the density:

  i.e. $(\Omega \cdot \text{m}) \times (\text{gm/m}^3) = \Omega \cdot \text{gm/m}^2$

- Length resistivity: this is the resistance of a conductor per unit length, i.e. Ω/m.
- Conductivity: therefore, the electrical conductivity with reference to say, volume conductivity, can be expressed by

  $$\frac{\text{m}}{\Omega \cdot \text{m}^2}$$

  or $\dfrac{1}{\Omega \cdot \text{m}}$ etc.

The resistivity and conductivity of standard annealed copper and a few recommended aluminium grades being used widely for electrical applications are given in Table 30.1. Their corresponding current-carrying capacities in

Table 30.1 Selected properties (average) of copper and aluminium at 20°C

Parameters		*Standard copper (IACS)*[a]	*Commercial purity aluminium (for electrical use)*		
			1	2	3
Relevant Standards		IEC 60028	← IEC 60105 ISO 209-1,2 →		
Standard grades (a) As in BS (b) As in BS 2898 (ISO 209-1) (c) Equivalent Indal grades		 100% IACS – –	 EIE[c] – M[b] 1350 CIS – M[b]	 HE9[c] – WP[b] 6063 A 50S – WP[b]	 E – 91E[c] 6101A D 50S – WP[b]
Physical properties (a) Chemical composition					
	Copper (Cu) %	99.9% pure	Cu, Si, Fe – Not more than 0.5%	0.1	0.05
	Magnesium (Mg) %		Mg, Cr, Sn, Zn and Mn ≃ Nil	0.6–0.9	0.4–0.9
	Silicon (Si) %			0.3–0.6	0.3–0.7
	Iron (Fe) %			0.15–0.35	0.4
	Cr, Ti, Zn and Mn %			0.6	0.1
	Aluminium	–	99.5%	← Rest is all aluminium →	
Specific heat	gm.cal/°C	0.092	← 0.220 →		
Density	(gm/cm^3)	8.89	2.71	2.70	2.71
Melting point	(°C)	1083	← 660 →		
Mechanical properties					
Ultimate tensile strength	kgf/mm^2	22 to 26	6.5/7.0	15.5/23.5	20.5/25
Ultimate shearing strength	kgf/mm^2	16 to 19	5.5	16.5	15
Modulus of elasticity E	kgf/mm^2	12,000	7000	6700	6700
0.2% tensile-proof strength	kgf/mm^2	60–80% of the tensile strength	–	11/19.5	16.5/22
Electrical properties Volume resistivity or specific resistance (ρ)					
	(a) in $\mu \cdot \Omega \cdot$ cm.	1.7241	2.873	3.1/3.6	3.133
	(b) in $\frac{\Omega \cdot mm^2}{m}$	1.7241×10^{-2}	2.873×10^{-2}	$3.1 \times 10^{-2}/3.6 \times 10^{-2}$	3.133×10^{-2}

Parameters		*Standard copper (IACS)*[a]	*Commercial purity aluminium (for electrical use)*		
Volume conductivity	m/Ω·mm^2	58	34.80	32.26/27.8	31.90
Conductivity	% IACS*	100	61/60	50/48	55
Temperature coefficient of electrical resistance per °C (applicable over a working range of 100–200°C) α_{20} at a particular conductivity = α_{20} at 100% conductivity × actual conductivity of the metal	α_{20}	3.93×10^{-3}	$4.03 \times 10^{-3}/3.96 \times 10^{-3}$	$3.3 \times 10^{-3}/3.168 \times 10^{-3}$	3.63×10^{-3}
Coefficient of linear expansion (thermal), (applicable over a working range of 20–200°C)	(mm/°C)	1.73×10^{-5}	2.3×10^{-5}	2.3×10^{-5}	2.3×10^{-5}
Mass resistivity = volume resistivity × density	(μ·Ω·gm/cm^2)	15.328	7.786	8.37/9.72	8.49

Notes
1 When using the above metals for the purpose of current carrying, their mechanical suitability must be checked with the data provided above to withstand, without permanent deformation, the electrodynamic forces that may develop during a short-circuit condition (Section 28.4.2).
2 For important definitions, refer to Section 30.1.1.
3 These values are based on the mean values of a number of tests carried out on specimens of standard copper and aluminium conductors.

[a] IACS – International Annealed Copper Standard
[b] Suffix M (now F) or WP (now T_6) represents the type of tempering.
[c] EIE, HE9 and E91E are old designations. They have now been replaced by 1350, 6063 A and 6101 A respectively.

per cent, with respect to a standard reference (say, 100% IACS) are also provided in the table.

30.1.4 Measuring the conductivity

For this purpose, a simple conductivity meter based on the principle of eddy current may be used for a direct reading of conductivity. The meter operates on the basis of relative variance, in the impedance of the test piece compared to the reference standard piece of aluminium or copper having a conductivity of 100% or 31.9 m/Ωmm^2 for aluminium and 58.0 m/Ωmm^2 for IACS (International Annealed Copper Standard) in terms of conductivity unit. The test probes, that sense the impedance of the test piece, induce an eddy current in the test piece at a fixed frequency. The magnitude of this current is directly proportional to the conductivity of the metal. This eddy current develops an electromagnetic field around the test piece and varies the impedance of the test probe (skin effect). The conductivity is thus determined by measuring the corresponding change in the impedance of the probe. Figure 30.2 shows a simple and portable conductivity meter.

30.2 Current-carrying capacity of copper and aluminium conductors

Earlier practice was to use copper in most applications in view of its rigidity and high conductivity. With the easier availability of aluminium and being more viable economically, aluminium is now preferred wherever possible. It is employed particularly where the metal has to simply carry power such as for the transmission and distribution of power at any voltage and as the main current-carrying conductor in power distribution or control equipment, such as a bus system or a switchgear assembly. Similarly, it is also used to feed high currents to an induction or a smelting furnace, electroplating plant or a rectifier plant. For main current-carrying components, however, as required for switching or interrupting devices (breakers, switches, fuses, contactors and relays) copper and copper alloys are preferred. The alloys of copper are compact in size and are a much harder metal, suitable for making and breaking contacts frequently and yet retaining their shape and size over long years of operation. Copper is also used for low ratings, up to 100 A or so, required for the internal wiring of power and control circuits in a switchgear or a controlgear assembly, where the wires have to bend frequently. Aluminium, being brittle, is unsuitable for such applications. The use of copper is also recommended for areas that are humid, saline and chemically aggressive which may corrode aluminium quickly. As aluminium is highly oxidizing and a very susceptible metal to such environments it may loosen at the joints. Typical locations are mines, ships, textile mills and chemical and petrochemical processing units. But for such applications also, the latest practice is to instal electrical equipment and switchgears in separate rooms, away from the affected areas, thus making it possible to use aluminium. In the following tables we have provided data for both copper and aluminium conductors. Copper current ratings are shown in Tables 30.2 (a, b and c) for flat bars, tubes and channel sections respectively. Derating factors as shown in Table 30.3 may be applied to account for skin effect when more than one bar is used in parallel. No separate skin effect factor need be calculated when this factor is applied.

Below we give the recommended sizes and ratings:

- Copper wires/cables: refer to Table 13.15 for current ratings up to 100 A, as recommended for the internal wiring of a power switchgear or a controlgear assembly.
- Copper solid conductors: Tables 30.2 a, b and c and 30.3 for general engineering purposes.
- Aluminium solid conductors: Tables 30.4, 30.5, 30.6, 30.7, 30.8 and 30.9 for general engineering purposes.

The following factors must be taken into account while deciding on the most appropriate and economical sections of the metal conductors for the required current rating;

For the same thickness, a smaller cross-section will have a relatively higher heat-dissipating area compared to a larger cross-section. The latter therefore will have a higher deration compared to a smaller cross-section on account of poorer heat dissipation. This can be illustrated as follows.

Consider a 25.4 × 6.35 mm conductor with a cross-sectional area of 25.4 × 6.35 mm^2 and a surface area of 2 (25.4 + 6.35) × l (l being the length, in mm) = 63.5l mm^2.

A conductor with twice the width (i.e. 50.8 × 6.35 mm) will have a cross-sectional area of 50.8 × 6.35 mm^2, and a surface area of 2 (50.8 + 6.35) × l = 114.3l mm^2. Thus the larger section having twice the cross-sectional area in the same thickness will have 114.3/(2 × 63.5) or only 90% surface area compared to the smaller section and consequently less heat dissipation in the same ratio and will require a higher derating.

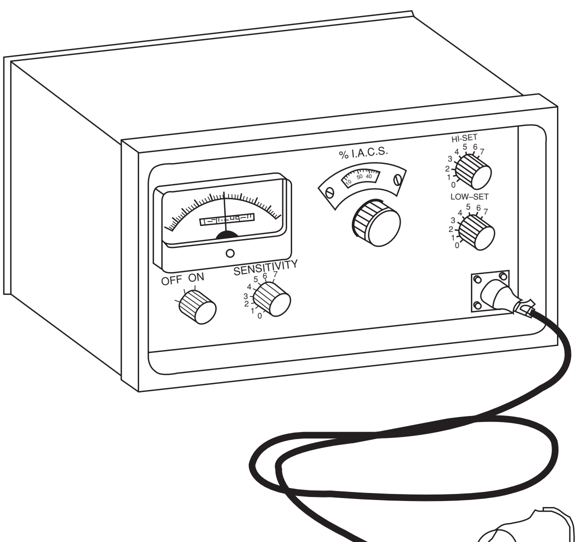


Figure 30.2 Conductivity meter (Courtesy: Technofour)

Corollary

1 Thinner sections will have a relatively higher surface

Tables of properties of high conductivity (HC) copper conductors

Table 30.2a Current ratings, moments of inertia and section moduli for strips and bars
(For more sections see CDA Pub.22)

Busbar size mm	X-Sectional area mm^2	Weight kg/m	Approx d.c. resistance 20°C μΩ/m	Approx. d.c. rating: Still air A	Approx. d.c. rating: Free air A	Approx. a.c. rating: Still air A	Approx. a.c. rating: Free air A	Moment of inertia, I: Edgewise mm^4	Moment of inertia, I: Flat mm^4	Modulus of Section, Z: Edgewise mm^3	Modulus of Section, Z: Flat mm^3	Busbar size mm
12.5 × 4.0	50	0.446	344	210	230	210	230	651.0	66.67	104.2	33.34	12.5 × 4.0
25 × 4.0	100	0.893	172	365	410	365	410	5208	133.3	416.6	66.65	25 × 4.0
50 × 4.0	200	1.785	86.2	665	740	660	735	41660	266.7	1666	133.4	50 × 4.0
80 × 4.0	320	2.856	53.8	995	1120	980	1105	170×10^3	426.7	4268	213.4	80 × 4.0
100 × 4.0	400	3.571	43.1	1210	1365	1185	1340	333×10^3	533.3	6666	266.7	100 × 4.0
12.5 × 6.3	78.75	0.703	218	275	305	275	305	1025	260.5	164.0	82.70	12.5 × 6.3
25 × 6.0	150	1.339	114	460	515	460	515	7813	450.0	625.0	150.0	25 × 6.0
50 × 6.0	300	2.678	57.4	825	915	815	910	62500	900.0	2500	300.0	50 × 6.0
80 × 6.0	480	4.285	35.9	1230	1370	1220	1355	256×10^3	1440	6400	480.0	80 × 6.0
100 × 6.0	600	5.356	28.7	1490	1680	1480	1670	500×10^3	1800	10000	600.0	100 × 6.0
120 × 6.0	720	6.428	23.9	1750	1970	1700	1915	864×10^3	2160	14400	720.0	120 × 6.0
160 × 6.0	960	8.570	17.9	2250	2535	2130	2400	2.05×10^6	2880	25600	960.0	160 × 6.0
25 × 8.0	200	1.785	86.2	545	610	545	605	10420	1067	833.6	266.7	25 × 8.0
50 × 8.0	400	3.571	43.1	965	1070	950	1055	83300	2133	3333	533.3	50 × 8.0
80 × 8.0	640	5.713	26.9	1435	1595	1420	1580	341×10^3	3413	8533	853.3	80 × 8.0
100 × 8.0	800	7.142	21.5	1735	1955	1595	1800	667×10^3	4267	13330	1067	100 × 8.0
120 × 8.0	960	8.570	17.9	2032	2290	1760	1985	1.15×10^6	5120	19200	1280	120 × 8.0
160 × 8.0	1280	11.43	13.4	2610	2935	2230	2510	2.73×10^6	6827	34140	1707	160 × 8.0
200 × 8.0	1600	14.27	10.8	3170	3570	2760	3110	5.33×10^6	8533	53330	2133	200 × 8.0
25 × 10	250	2.232	68.9	625	695	580	645	13020	2083	1042	416.6	25 × 10
50 × 10	500	4.464	34.4	1090	1235	1060	1200	104×10^3	4167	4168	833.4	50 × 10
80 × 10	800	7.142	21.5	1615	1840	1525	1735	427×10^3	6667	10670	1333	80 × 10
100 × 10	1000	8.928	17.2	1950	2225	1800	2065	833×10^3	8333	16670	1667	100 × 10
120 × 10	1200	10.71	14.3	2285	2610	2100	2395	144×10^3	10000	23980	2000	120 × 10
160 × 10	1600	14.28	10.7	2930	3380	2620	3040	341×10^3	13330	42660	2666	160 × 10

Table 30.2a *(Contd.)*

Busbar size	X-Sectional area	Weight	Approx d.c. resistance 20°C	Approx. d.c. rating		Approx. a.c. rating		Moment of inertia, I		Modulus of Section, Z		Busbar size
				Still air	Free air	Still air	Free air	Edgewise	Flat	Edgewise	Flat	
mm	mm^2	kg/m	μΩ/m	A	A	A	A	mm^4	mm^4	mm^3	mm^3	mm
200 × 10	2000	17.84	8.62	3550	4150	3140	3630	6.67×10^6	16670	66670	3334	200 × 10
250 × 10	2500	22.30	6.89	4320	5030	3710	4310	13.0×10^6	20830	104×10^3	4166	250 × 10
25 × 12	300	2.678	57.4	700	710	640	650	15630	3599	1250	599.8	25 × 12
50 × 12	600	5.356	28.7	1210	1330	1160	1275	125×10^3	7199	5000	1199	50 × 12
80 × 12	960	8.570	17.9	1785	2000	1670	1870	512×10^3	11519	12800	1919	80 × 12
100 × 12	1200	10.71	14.3	2155	2420	2010	2255	1.00×10^6	14390	20000	2398	100 × 12
120 × 12	1440	12.85	11.9	2520	2880	2310	2640	1.73×10^6	17280	28800	2880	120 × 12
160 × 12	1920	17.14	8.97	3225	3650	2860	3235	4.10×10^6	23040	51200	3840	160 × 12
200 × 12	2400	21.43	7.18	3910	4480	3380	3870	8.00×10^6	28790	80000	4798	200 × 12
250 × 12	3000	26.78	5.74	4750	5440	4060	4650	15.6×10^6	35990	125×10^3	5998	250 × 12

Based on Copper Development Association, Pub. 22

Notes

1. The ratings are based on a 50°C rise over 40°C ambient temperature in still but unconfined air.
2. AC ratings are for frequencies up to 60 Hz. At 50 Hz ratings may be enhanced by 2.5–5% in large cross-sections (see Section 28.7.2).
3. AC ratings are based on spacings at which the proximity effect is considered almost negligible (≥ 300 mm Section 28.8).
4. These are the basic maximum ratings, that a current-carrying conductor can carry under ideal operating conditions. The rating is influenced by the service conditions and other design considerations, as discussed in Section 28.5. Apply suitable derating factors to arrive at the actual current ratings of these conductors under actual operating conditions.
5. Ratings may be improved by approximately 20% if the busbars are painted black with a non-metallic matt finish paint. This is because heat dissipation through a surface depends upon temperature, type of surface and colour. A rough surface dissipates heat more readily than a smooth surface and a black body more quickly than a normal surface. Also refer to Section 31.4.4 and Table 31.1. Black paint also prevents the metal from oxidation and improves cooling. Oxidation is a thermal insulating film and a hindrance in the natural heat dissipation.
6. The above ratings are for single bars. When multiple bars are used, apply the skin effect factor as per Table 30.3. This factor will account for the restricted heat dissipation and additional skin effect due to the large number of bars.

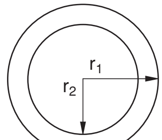


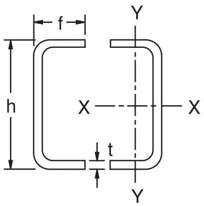
Table 30.2b Current ratings, moments of inertia and section moduli for tubes
(For more metric and imperial sections and rods see CDA Pub. 22)

Outside diameter	*Wall thickness*	*Cross sectional area*	*Approx. weight*	*Moment of inertia of section*	*Modulus of section*	*Approx. resistance per m 20°C*	*Approx. d.c. current rating*	
mm	*mm*	*mm*^{2}	*kg/m*	*mm*^{4}	*mm*^{3}	$\mu\Omega$	*Indoor A*	*Outdoor A*
22	1.0	65.98	0.587	3645	331.4	263	320	410
22	1.5	96.61	0.859	5102	463.8	179	385	500
22	2.0	125.7	1.12	6346	576.9	138	440	570
22	2.5	154.1	1.37	7399	672.7	112	490	630
22	3.0	179.1	1.59	8282	752.9	97.0	525	680
28	1.5	124.9	1.11	11000	785.5	139	480	620
28	2.0	163.4	1.45	13890	991.8	106.3	550	700
28	2.5	200.3	1.78	16440	1157	86.7	605	780
28	3.0	235.6	2.10	18670	1334	73.7	660	850
35	1.5	157.9	1.40	22190	1268	110	585	750
35	2.0	207.4	1.84	28330	1619	83.7	670	850
35	2.5	255.3	2.27	33900	1937	68.0	740	950
35	3.0	301.6	2.68	38940	2225	57.5	805	1030
54	1.5	247.4	2.20	85300	3160	70.2	855	1090
54	2.0	326.7	2.91	110600	4096	53.1	980	1250
54	2.5	404.5	3.60	134400	4978	42.9	1090	1390
54	3.0	480.7	4.27	156800	5808	36.1	1190	1520
76.1	2.0	465.6	4.14	319800	8404	37.3	1330	1690
76.1	2.5	578.1	5.14	392000	10300	30.0	1480	1880
76.1	3.0	689.0	6.13	461000	12110	25.2	1610	2050
76.1	3.5	798.3	7.10	527200	13850	21.7	1740	2210
108	2.5	828.6	7.37	1.153×10^6	21360	20.9	2010	2550
108	3.0	989.6	8.80	1.365×10^6	25280	17.5	2190	2790
108	3.5	1149	10.2	1.570×10^6	29080	15.1	2360	3010
133	3.0	1225	10.9	2.590×10^6	38940	14.1	2630	3350
133	3.5	1424	12.7	2.987×10^6	44920	12.1	2830	3610
159	3.0	1470	13.1	4.474×10^6	56280	11.8	3070	2910
159	3.5	1710	15.2	5.171×10^6	65040	10.1	3310	4420

Based on Copper Development Association, Pub. 22

Notes

1. The ratings are based on a 50°C rise over 40°C ambient temperature in still but unconfined air.
2. AC ratings are for frequencies up to 60 Hz. At 50 Hz ratings may be enhanced by 2.5–5% in large cross-sections (see Section 28.7.2).
3. AC ratings are based on spacings at which the proximity effect is considered almost negligible (≥300 mm Section 28.8)
4. These are the basic maximum ratings, that a current-carrying conductor can carry under ideal operating conditions. The rating is influenced by the service conditions and other design considerations, as discussed in Section 28.5. Apply suitable derating factors to arrive at the actual current ratings of these conductors under actual operating conditions.
5. Ratings may be improved by approximately 20% if the busbars are painted black with a non-metallic matt finish paint. This is because heat dissipation through a surface depends upon temperature, type of surface and colour. A rough surface dissipates heat more readily than a smooth surface and a black body more quickly than a normal surface. Also refer to Section 31.4.4 and Table 31.1. Black paint also prevents the metal from oxidation and improves cooling. Oxidation is a thermal insulating film and a hindrance in the natural heat dissipation.
6. The above ratings are for single bars. When multiple bars are used, apply the skin effect factor as per Table 30.3. This factor will account for the restricted heat dissipation and additional skin effect due to the large number of bars.



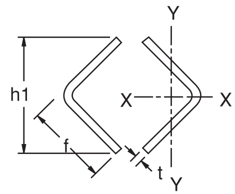


Table 30.2c Current ratings, moments of inertia and section moduli for channel sections

					ONE CHANNEL					*TWO CHANNELS*	
Height h	*Width of flange f*	*Thickness t*	*Area A*	*Approx. weight*[c]	*Moment of inertia x–x*	*Moment of inertia y–y*	*Modulus of section x–x*	*Modulus of section y–y*	*Approx. d.c. resistance at 20°C*	*Approx a.c. rating Test*[a]	*Approx a.c. rating Calculated*[b]
mm	*mm*	*mm*	*mm*^{2}	*kg/m*	$\times 10^5$ *mm*^{4}	$\times 10^5$ *mm*^{4}	$\times 10^5$ *mm*^{3}	$\times 10^5$ *mm*^{3}	*μΩ/m*	*A*	*A*
76.2	33.3	4.91	542	4.82	5.06	0.543	0.133	0.0226	31.8	2200	3000
76.2	33.3	5.49	690	6.15	6.30	0.673	0.165	0.0286	24.9	2500	3400
76.2	33.3	7.21	884	7.86	7.78	0.822	0.204	0.0358	19.5	2800	3800
102	44.5	5.08	890	7.92	14.5	1.60	0.286	0.0497	19.4	3200	4400
102	44.5	6.10	1050	9.35	16.9	1.86	0.333	0.0583	16.4	3500	4800
102	44.5	8.59	1430	12.7	22.3	2.42	0.439	0.0780	12.0	4000	5550
127	55.6	6.60	1450	12.9	36.4	4.05	0.573	0.102	11.9	4500	6150
127	55.6	8.61	1850	16.4	45.4	5.02	0.796	0.127	9.35	5000	6850
152	68.3	7.01	1850	16.8	68.9	7.30	0.901	0.147	9.15	5600	7700
152	68.3	9.75	2550	22.7	90.9	10.7	1.19	0.220	6.76	6300	8600
152	68.3	12.5	3180	28.3	111	12.9	1.45	0.270	5.41	6700	9200
178	81.0	8.26	2610	23.2	129	15.9	1.46	0.272	6.59	7000	9650
178	81.0	13.2	4010	35.7	191	23.7	2.18	0.417	4.29	7900	10850
203	81.0	11.9	4280	38.0	272	34.3	2.68	0.513	4.04	8900	12300
228	105	12.7	5140	45.7	413	51.7	3.61	0.688	3.35	10000	13750
89.9	63.5 × 63.5	4.76	542	4.81	3.62	0.957	0.0806	0.0533	31.8	2750	3000
108	76.2 × 76.2	4.76	671	5.95	6.41	1.71	0.119	0.0583	35.7	3300	3600
108	76.2 × 76.2	6.35	910	8.08	8.08	1.92	0.150	0.0637	18.9	3650	4100
126	88.9 × 88.9	6.35	1070	9.52	13.3	3.33	0.211	0.0957	16.1	4200	4500
144	102 × 102	6.35	1230	10.9	17.5	5.00	0.243	0.128	14.1	4800	5200
162	114 × 114	6.35	1390	12.3	29.1	7.33	0.359	0.167	12.4	5400	5850
162	114 × 114	7.94	1650	14.7	35.5	9.20	0.439	0.208	10.4	6000	6550
180	127 × 127	7.94	1850	16.4	49.2	12.4	0.549	0.251	9.32	6750	7400
216	152 × 152	7.94	2260	20.1	86.5	21.6	0.803	0.370	7.61	8000	8700

Based on Copper Development Association, Pub. 22

[a] 30°C rise over 40°C ambient
[b] 50°C rise over 40°C ambient. For approximate values for ambients below or above 40°C increase or decrease rating by 0.25% per °C respectively.
[c] Weights based on copper density of 8.89 g/cm^3

Notes
As in Table 30.2a

Table 30.3 Multiplying factors for copper sections

No. of bars	*Multiplying factor*
1	1.0
2	1.8
3	2.5
4	3.2
5	3.9
6	4.4
8	5.5

Source: Copper Development Association, Pub. 22.

Note

The space between the bars is considered to be equal to the thickness of the bars.

area to dissipate heat compared to thicker sections. The thinner the section, the better will be metal utilization and vice versa.

2 More bars in parallel will reduce the heat dissipation further and will require yet higher deratings.

3 Skin effect – the same theory is usually true for the skin effect. The thinner the surface, the smaller will be the nucleus resulting in a higher concentration of current at the surface and better utilization of metal.

We can derive the same inference from Tables 30.2(a, b and c), 30.4 and 30.5, specifying current ratings for different cross-sections. The current-carrying capacity varies with the cross-section not in a linear but in an inconsistent manner depending upon the cross-section and the number of conductors used in parallel. It is not possible to define accurately the current rating of a conductor through a mathematical expression. This can be established only by laboratory tests.

Mechanical and electrical data for important rectangular, circular and channel sections are also provided in Tables 30.2a, b and c for copper and Tables 30.7, 30.8 and 30.9 for aluminium conductors respectively for reference. For more details one may contact the manufacturer.

Table 30.4 Current ratings for rectangular aluminium sections, grade E91-E (6101 A)

Size mm	*1 bar D.C.*	*1 bar 50 Hz A.C.*	*2 bars D.C.*	*2 bars 50 Hz A.C.*	*3 bars D.C.*	*3 bars 50 Hz A.C.*	*4 bars D.C.*	*4 bars 50 Hz A.C.*
	Approximate ratings (A)							
25.4 × 6.35	355	355	710	705	980	970	1120	1100
38.1 × 6.35	520	520	1030	1020	1380	1350	1585	1535
50.8 × 6.35	670	670	1315	1290	1765	1705	2050	1940
63.5 × 6.35	820	810	1550	1510	2100	2000	2430	2260
76.2 × 6.35	970	960	1805	1740	2440	2310	2860	2620
101.6 × 6.35	1260	1235	2260	2140	3060	2800	3640	3200
127.0 × 6.35	1545	1505	2700	2510	3660	3240	4410	3700
152.4 × 6.35	1840	1780	3130	2860	4290	3680	5250	4240
50.8 × 9.53	840	830	1560	1500	2090	1970	2460	2260
76.2 × 9.53	1210	1180	2180	2050	2940	2660	3510	3030
101.6 × 9.53	1550	1495	2710	2480	3660	3150	4400	3560
127.0 × 9.53	1940	1860	3290	2930	4450	3660	5400	4200
152.4 × 9.53	2260	2120	3770	3340	5140	4080	6300	4680
203.2 × 9.53	2940	2750	4800	4150	6500	4900	8060	5740
76.2 × 12.7	1405	1355	2450	2240	3290	2830	4000	3240
101.6 × 12.7	1830	1740	3100	2720	4170	3360	5100	3900
127.0 × 12.7	2230	2080	3720	3120	5040	3900	6170	4550
152.4 × 12.7	2620	2420	4300	3500	5850	4400	7200	5100
203.2 × 12.7	3380	3060	5450	4450	7420	5300	9110	6150
254.0 × 12.7	4080	3640	6500	5000	8860	6000	10900	6850

Source: Indalco

Notes

1 The ratings are indicative and based on a 50°C rise over 35°C ambient temperature in still but unconfined air.

2 For a multiple-bar arrangement, the space between the bars is considered to be equal to the thickness of the bar.

3 A.C. ratings are based on spacings, at which the proximity effect is considered almost negligible (≥ 300 mm, Section 28.8).

4 These are the basic maximum ratings that a current-carrying conductor can carry under ideal operating conditions. They are influenced by the service conditions and other design considerations, as discussed in Section 28.5. Apply suitable derating factors to arrive at the actual current ratings of these conductors under actual operating conditions.

5 Ratings may be improved approximately by 20% if the busbars are painted black with a non-metallic matt finish paint. This is because the heat dissipation through a surface depends upon its temperature, type of surface and colour. A rough surface dissipates heat more readily than a smooth surface and a black body more quickly than a normal surface. See also Section 31.4.4 and Table 31.1. Black paint also prevents the metal from oxidation and improves cooling. Oxidation is a thermal insulating film and a hindrance in the natural heat dissipation.

6 Other grades as in BS EN 755-3 (ISO 209–1,2), for electrical purposes, and as produced by the leading manufacturers, are provided in Table 30.6.

7 To obtain the current rating for any other grade of busbar, multiply the above figures by the appropriate factor defined in Table 30.6.

Table 30.5 Current ratings for rectangular aluminium sections, Grade EIE-M (1350)

Conductor size (mm)	*Cross-sectional area (mm²)*	*1 bar*	*2 bars*	*3 bars*	*4 bars*	*5 bars*	*6 bars*
		Approximate ratings (A)					
2.5 × 12	30	118	210	285	360	425	480
16	40	151	275	395	490	580	655
20	50	183	320	450	575	675	770
25	62.5	223	390	540	685	800	910
30	75	263	480	660	840	990	1115
40	100	342	610	860	1080	1260	1425
4 × 12	48	156	290	420	536	620	700
16	64	198	340	470	600	710	815
20	80	238	410	570	720	850	955
25	100	290	530	755	950	1110	1250
30	120	339	600	845	1060	1245	1400
40	160	434	750	1050	1320	1550	1750
50	200	532	905	1260	1575	1825	2035
6 × 12	72	200	350	480	610	720	825
16	96	252	450	640	805	960	1075
20	120	301	550	790	1000	1170	1320
25	150	364	640	900	1120	1315	1485
30	180	424	730	1025	1290	1520	1720
40	240	545	935	1310	1630	1900	2130
50	300	660	1130	1580	1950	2255	2505
60	360	782	1350	1870	2200	2630	2885
80	480	995	1700	2310	2745	3070	3330
100	600	1215	2090	2770	3190	3490	3745
120	720	1415	2415	3180	3640	3985	4270
160	960	1830	3100	4050	4600	5025	5340
10 × 40	400	720	1230	1710	2110	2425	2670
50	500	870	1500	2060	2505	2850	3100
60	600	1015	1750	2350	2795	3120	3380
80	800	1250	2215	2940	3355	3675	3950
100	1000	1565	2650	3465	3940	4315	4635
120	1200	1810	3050	4010	4560	4980	5290
160	1600	2310	3940	5170	5870	6300	6620
200	2000	2795	4750	6160	–	–	–
250	2500	3365	5720	–	–	–	–
16 × 100	1600	1950	3260	4250	4890	5340	5660
120	1920	2255	3850	5030	5700	6130	6450
160	2560	2840	4830	6260	–	–	–
200	3200	3395	5780	–	–	–	–
250	4000	4095	6500	–	–	–	–

Source: The Aluminium Federation

Notes

1 Current ratings for E-91E (6101 A) bars are about 3% lower than EIE-M (1350); refer to Table 30.6.
2 The ratings are indicative and based on a 50°C rise over 35°C ambient temperature in still but unconfined air.
3 For a multiple-bar arrangement the space between the bars is considered to be equal to the thickness of the bar.
4 AC ratings are based on spacings at which the proximity effect is considered almost negligible (≥ 300 mm, Section 28.8).
5 These are the basic maximum ratings that a current-carrying conductor can carry under ideal operating conditions. They are influenced by the service conditions and other design considerations, as discussed in Section 28.5. Apply suitable derating factors to arrive at the actual current ratings of these conductors under actual operating conditions.
6 Ratings may be improved approximately by 20% if the busbars are painted black with a non-metallic matt finish paint. This is because, the heat dissipation through a surface depends upon its temperature, type of surface and colour. A rough surface dissipates heat more readily than a smooth surface and a black body more quickly than a normal body. See also Section 31.4.4 and Table 31.1. Black paint also prevents the metal from oxidation and improves cooling. Oxidation is a thermal insulating film and a hindrance in the natural heat dissipation.
7 Other grades as in BS EN 755–3 (ISO 209–1, 2), for electrical purposes, and as produced by the leading manufacturers, are provided in Table 30.6.
8 To obtain the current rating for any other grade of busbar, multiply the above figures by the appropriate factor defined in Table 30.6.

Table 30.6 Grades of aluminium alloys for electrical purposes

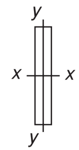
Grades as the old designation	*Grades as in BS EN 755-3 (ISO 209-1)*	*Equivalent grades of Indian Aluminium (Indal) alloys*	*Multiplying factor to ratings of Table 30.4*
EIE–M	1350	CIS–M	1.03
EIC–M	–	2 S–M	1.02
E–91E	6101 A	D 50 S–WP	1.00
HE–9–WP	6063 A	50 S–WP	0.94

Notes

1 Aluminium conductors for engineering application are produced in commercial grade quality, having an electrical conductivity varying from 70% to 94% (approx.) as well as electrical grade quality having a purity in electrical conductivity as 94% and higher, as noted above, varying slightly from manufacturer to manufacturer. Commercial grade, not below HE–9–WP (6063A), can be used for current carrying, say, up to 1000 A, although electrical grade is preferred. For higher currents, however, electrical grade only should be preferred.

2 When the short-circuit forces are likely to be high, say, 1500 kgf or more, per metre run, such as on a main power circuit the electrolytic grade aluminium of type EIE–M (1350) may not be recommended. It is a soft metal mechanically, as noted in Table 30.1, which will require busbar supports at very close spacing, defeating the economics of the selection. The grade type E-91E (6101 A), which has a better mechanical strength, would be a better choice for all types of power applications. The selection of busbars, shape and grade, is thus governed by mechanical considerations and economics, rather than the purity of the alloy alone.

Table 30.7 Indal CIS - M and D 50 S - WP rectangular busbars equivalent to EIE - M (1350) and E - 91E (6101 A) as in BS EN 755-3 (ISO 209-1,2) (mechanical and electrical data)



Size	*Cross-sectional area*	*Weight*	*CISM d.c. resistance (max.) at 20°C*	*D 50 SWP d.c. resistance (max.) at 20°C*	*Reactance X_a at 305 mm spacing at 50 Hz*	*Moment of inertia*		*Section modulus*		*Radius of gyration*	
mm	*mm^2*	*kg/m*	*μΩ/m*	*μΩ/m*	*μΩ/m*	*(cm^4) Ix–x*	*(cm^4) Iy–y*	*(cm^3) Zx–x*	*(cm^3) Zy–y*	*(cm) Kx–x*	*(cm) Ky–y*
25.4 × 6.35	161.29	0.435	178.15	194.35	236.22	0.874	0.012	0.688	0.131	0.734	0.183
38.1 × 6.35	241.30	0.652	118.76	129.56	215.22	2.914	0.033	1.540	0.262	1.102	0.183
50.8 × 6.35	322.58	0.871	89.07	97.18	199.14	6.951	0.125	2.737	0.393	1.468	0.183
63.5 × 6.35	403.23	1.089	71.26	77.82	186.35	13.569	0.125	4.261	0.426	1.836	0.183
76.2 × 6.35	483.87	1.306	59.38	64.80	175.85	23.434	0.166	6.145	0.508	2.202	0.183
101.6 × 6.35	645.16	1.742	44.55	48.59	159.45	55.484	0.208	10.930	0.688	2.936	0.183
127.0 × 6.35	806.45	2.177	35.63	38.88	146.00	108.387	0.291	17.075	0.852	3.670	0.183
152.4 × 6.35	967.74	2.613	29.69	32.38	134.51	187.304	0.333	24.581	1.032	4.404	0.183
50.8 × 9.53	484.12	1.307	59.38	64.80	195.86	10.406	0.374	4.097	0.787	1.466	0.274
76.2 × 9.53	726.19	1.961	39.60	43.18	174.21	35.130	0.541	9.226	1.147	2.202	0.274
101.6 × 9.53	968.25	2.614	29.69	32.38	157.48	83.246	0.749	16.387	1.540	2.936	0.274
127.0 × 9.53	1210.31	3.268	23.75	26.21	144.36	162.580	0.916	25.613	1.917	3.670	0.274
152.4 × 9.53	1452.37	3.921	19.82	21.59	134.18	280.956	1.082	36.871	2.311	4.404	0.274
203.2 × 9.53	1936.50	5.228	14.83	16.21	117.45	665.970	1.457	65.548	3.064	5.872	0.274
76.2 × 12.70	967.74	2.613	29.69	32.38	170.93	46.826	1.290	12.290	2.048	2.202	0.368
101.6 × 12.70	1290.32	3.848	22.28	24.28	155.84	111.009	1.748	21.844	2.737	2.936	0.368
127.0 × 12.70	1612.90	4.355	17.81	19.42	143.04	216.773	2.164	34.134	3.409	3.670	0.368
152.4 × 12.70	1935.48	5.226	14.83	16.21	132.54	374.608	2.622	49.161	4.097	4.404	0.368
203.2 × 12.70	2580.64	6.968	11.12	12.14	115.81	887.822	3.455	87.376	5.441	5.872	0.368
254.0 × 12.70	3225.80	8.710	8.89	9.71	96.78	1734.436	4.329	136.570	6.817	7.341	0.368

Source: Indalco

Notes
As in Table 30.4

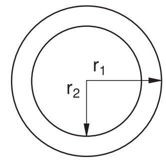


Table 30.8 Indal D50S WP tubular busbars (mechanical and electrical data and current rating)

Pipe nominal size IPS	*Nominal diameter*		*Wall thickness*	*Area*	*Nominal weight*	*Moment of inertia*	*Section modulus*	*Radius of gyration*	*G.M.D. Ds.*	*D.C. resistance (max.) at 20°C*	*Reactance X_a at 300 mm spacing at 50 Hz*	*Current rating at 50 Hz (Amps)*	
	Outside	*Inside*										*Indoors*	*Outdoors*
in.	*mm*	*mm*	*mm*	mm^2	*kg/m*	cm^4	cm^3	*cm*	*cm*	*μΩ/m*	*μΩ/m*		
(standard pipe sizes)													
1	33.40	26.64	3.38	319	0.861	3.634	0.857	1.068	1.560	98.1	186.7	675	815
$1^1/_4$	42.16	35.04	3.56	432	1.166	8.104	3.844	1.371	1.991	72.7	171.3	845	1010
$1^1/_2$	48.26	40.90	3.68	515	1.392	12.899	5.345	1.581	2.291	60.7	162.7	960	1160
2	60.33	52.51	3.91	693	1.871	27.709	9.186	1.999	2.878	45.1	148.3	1245	1440
$2^1/_2$	73.03	62.71	5.16	1100	2.970	63.683	17.451	2.406	3.475	28.4	136.2	1720	1950
3	88.90	77.92	5.49	1439	3.884	125.606	28.258	2.957	4.267	21.8	123.7	2130	2350
$3^1/_2$	101.60	90.12	5.74	1729	4.667	199.279	39.227	3.396	4.877	17.4	115.2	2510	2750
4	114.30	102.26	6.02	2048	5.529	301.039	52.675	3.835	5.514	15.3	107.6	2800	3050
$4^1/_2$	127.00	114.46	6.27	2379	6.423	434.683	68.454	4.275	6.160	13.2	100.1	3160	3420
5	141.30	128.20	6.55	2724	7.490	631.007	89.326	4.770	6.853	11.3	93.8	3550	3810
(extra-heavy pipe sizes)													
1	33.40	24.30	4.55	412	1.113	4.395	2.632	1.033	1.521	76.0	188.3	745	925
$1^1/_4$	42.16	32.46	4.85	568	1.535	10.064	4.774	1.330	1.951	55.1	172.6	975	1170
$1^1/_2$	48.26	38.10	5.08	689	1.861	16.283	6.748	1.537	2.245	45.4	164.0	1125	1335
2	60.33	49.25	5.54	954	2.575	36.125	11.977	1.947	2.835	32.9	149.3	1465	1680
$2^1/_2$	73.03	59.01	7.01	1454	3.926	80.183	21.954	2.347	3.414	21.5	137.1	1955	2230
3	88.90	73.66	7.62	1946	5.254	162.093	36.466	2.885	4.178	16.1	124.7	2470	2700
$3^1/_2$	101.60	85.44	8.08	2374	6.410	261.393	51.455	3.320	4.801	13.2	116.1	2850	3160
4	114.30	97.18	8.56	2844	7.678	399.998	69.989	3.752	5.431	11.0	108.3	3260	3590
$4^1/_2$	127.00	108.96	9.02	3343	9.027	584.938	92.115	4.183	6.045	9.4	100.7	3700	4040
5	141.30	122.24	9.53	3947	10.656	860.350	121.772	4.671	6.746	8.0	94.5	4190	4550

Source: Indalco

Notes

1 These data are indicative and provided for typical standard sizes from a manufacturer. Busbars larger than the above are generally not manufactured in tubular sections but in sections and configurations that are convenient by extrusion (Figure 31.15). By welding such sections, one can form any desired size of tubular or any other conductor shape (hexagonal or octagonal). Such large sections are required for isolated phase bus (IPB) systems, discussed in Chapter 31.

2 Other notes as in Table 30.4.

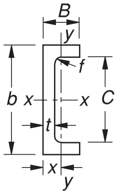
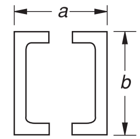


Table 30.9 Channel busbar: mechanical and electrical data and current ratings (Grade E – 91E)



					One channel										Two channels				
Size	*Web and flange thickness*	*Flange width*	*Inner flat surface*	*Fillet radius*	*Section area*	*Weight*	*Moment of inertia*		*Section modulus*		*Radius of gyration*		*Distance to neutral axis x*	*D.C. Resistance (max.) at 20°C*	*Depth*	*Width*	*Reactance at 305 mm spacing at 50 Hz*	*D.C. current rating*	*A.C. current rating at 50 Hz*
mm	*mm*	*mm*	*mm*	*mm*	*mm*^{2}	*kg/m*	*cm*^{4}		*cm*^{3}		*cm*		*mm*	*μΩ/m*	*mm*	*mm*	*μΩ/m*	*Amps*	*Amps*
b	*t*	*B*	*C*	*f*			*Ix – x*	*Iy – y*	*Zx – x*	*Zy – y*	*Kx – x*	*Ky – y*			*b*	*a*	X_a		
76.2	6.35	38.10	45.08	7.62	1013	2.735	77.42	12.07	20.48	4.59	2.84	1.12	11.9	33.07	76.2	100.0	114.83	3380	3340
101.6	6.68	41.83	69.20	9.52	1187	3.205	171.07	17.07	33.76	5.74	3.78	1.19	11.7	26.41	101.6	106.4	106.96	4250	4190
127.0	8.00	48.00	92.00	9.50	1695	4.576	375.44	31.63	59.16	9.18	4.70	1.37	13.2	18.41	127.0	127.0	92.52	5540	5440
152.4	8.10	51.66	113.98	11.11	1993	5.381	629.34	42.04	82.59	10.98	5.61	1.45	13.5	15.72	152.4	152.4	80.38	6500	6340
177.8	9.98	58.40	135.62	11.11	2794	7.544	1179.18	74.09	132.74	17.21	6.50	1.63	15.2	11.23	177.8	177.8	70.54	8200	7800
203.2	11.84	65.00	154.12	12.70	3734	10.082	2033.29	120.29	200.09	25.07	7.39	1.78	17.0	8.40	203.2	203.2	62.99	9850	9150
254.0	13.18	92.07	199.06	14.29	5515	14.89	4924.43	400.41	387.72	56.70	9.45	2.64	24.1	5.68	254.0	254.0	48.56	12800	11450

Source: Indalco

Notes
As in Table 30.4.

Relevant Standards

IEC	*Title*	*IS*	*BS*	*ISO*
60028/1925	International standard of resistance for copper.	–	–	–
60105/1958	Recommendation for commercial purity aluminium busbar material.	–	–	–
–	Copper rods and bars for electrical purposes.	613/2000	–	–
–	Wrought aluminium and aluminium alloys, drawn tubes for general engineering purposes.	738/1999	–	–
–	Aluminium and aluminium alloys, extruded rod/bar, tube and profiles.	1285/2002	BS EN 755 (8 parts)	–
–	Specification for copper strip for electrical purposes.	1897/2001	–	–
–	Copper for electrical purposes. Rods and bars.	4171/1988	BS 1433/1970	–
–	Specification for wrought aluminium and aluminium alloys for electrical purposes, bars, extruded round tube and sections.	5082/2003	BS EN 755-3/1996	209-1,2/1989
–	Specification for high conductivity copper tubes for electrical purposes.	–	BS EN 13600/2000	–
–	Copper for electrical purposes. High conductivity copper rectangular conductors with drawn or rolled edges.	–	BS EN 13601/2002	–

Notes

1 In the table of relevant Standards while the latest editions of the Standards are provided, it is possible that revised editions have become available or some of them are even withdrawn. With the advances in technology and/or its application, the upgrading of Standards is a continuous process by different Standards organizations. It is therefore advisable that for more authentic references, one may consult the relevant organizations for the latest version of a Standard.

2 Some of the BS or IS Standards mentioned against IEC may not be identical.

3 The year noted against each Standard may also refer to the year it was last reaffirmed and not necessarily the year of publication.

Further Reading

1 Alcoa, *Aluminium Bus Conductor Hand Book.*

2 British Aluminium Co. Ltd, *Aluminium Busbars,* Pub. No. L4.

3 British Aluminium Co. Ltd, *Aluminium for busbars, earthing and lightning conductors,* Pub. No. M4.

4 Copper Development Association, *Copper Busbar* (available in FPS and MKS systems), Pub. No. 22, U.K.

5 Dwight, H.B., *Electrical Coils and Conductors*, McGraw-Hill, New York (1945).

6 Indian Aluminium Co., *Indal Aluminium Busbar* (Collaborators Alcan, Canada).