DESIGN OF MACHINE PARTS

MATERIALS IN DESIGN OF MACHINE PARTS

STEEL AND STEEL STANDARDS

- **NATIONAL STEEL STANDARDS**
- Steel suppliers produce steels to various national standards
- Classified by application into categories shown in the next slide

STEEL

- An alloy of iron and carbon, in which the carbon content is less than 2.0 %.
- Other alloying elements present in steel are:
  - Silicon, Manganese, Chromium, Nickel, Molybdenum, Tungsten, Vanadium.
- Sulphur and Phosphorus occur as impurities originating from the ore and refining process.
- **CLASSIFICATION OF STEEL BY APPLICATION**
- The choice of steel for a particular application is initially made by choosing the carbon content. **The next slide** gives guidelines[1] on the carbon content suitable for various common applications.
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[1] *Shigley, Joseph E., Engineering Design, pp.222., McGraw-Hill Book C0mpany Inc., 1963.*

Uses for steel by carbon content

Carbon class	Carbon range, %	Use
Low	0.05-0.15	Chain, Nails, Pipe rivets, Sheets for pressing and stamping, wire
Medium	0.15-0.30	Bars, Plates, Structural shapes
	0.30-0.45	Axles, connecting rods, shafting
High	0.45-0.60	Crankshafts, scraper blades
	0.60-0.75	Automobile springs, Anvils, Band saws, Drop hammer dies
Very High	0.75-0.90	Chisels, punches, hand tools
	0.90-1.00	Knives, Shear blades, springs
	1.00-1.10	Milling Cutters, Dies, Taps
	1.10-1.20	Lathe Tools, Woodworking Tools
	1.20-1.30	Files, Reamers
	1.30-1.40	Dies for wire drawing
	1.40-1.50	Metal cutting saws

ALLOYING ELEMENTS EFFECTS ON STEEL

- **Chromium**
  - Increases hardness, without reducing ductility. Refines grain structure and increases toughness. Simplifies heat treatment requirements.
- **Nickel**
  - Increases strength without reducing ductility. Refines grain structure and increases toughness. Simplifies heat treatment requirements.
- **Manganese**
  - Added as a deoxidising and desulphurising agent. Considered as alloy when above 1 %. Enables oil quenching.
- **Silicon**
  - Added as a deoxidising agent. Stabilises carbides formed by other alloying elements

ALLOYING ELEMENTS EFFECTS ON STEEL

- **Molybdenum**
  - Improves oil hardening and air hardening properties. Used with Chromium and Nickel to simplify heat treatment
- **Vanadium**
  - Widely used in tool steels. Steel retains its hardness at high temperatures.
- **Tungsten**
  - Widely used in tool steels. Tool maintains its hardness even at red heat.

Limit of alloy content in plain carbon steels

- The distinction between plain carbon steels and alloy steels is based on the percentage by weight of the alloy content.
- For a single alloy element, the maximum value of alloy content above which the steel moves from plain to alloy classification are:
  - Chromium Cr, (0.3 %) ;
  - Manganese Mn, (1.6 %) ;
  - Molybdenum Mo, (0.08 %) ;
  - Nickel Ni, (0.3 %) ;
  - Silicon Si, (0.5 %) .
- when more than one alloy element is present simultaneously, then the limiting sum of the elements content is reduced to 70 % of the sum of the limits for individual alloy elements.

Classification of steels National Standards

	Application of the steel	Criterion for standard & supplier classification
1	Steels for general structural purposes	ultimate tensile strength (plain carbon steels)
2	Case hardening steels for general engineering purposes (Heat treatable)	carbon and alloy content (plain carbon & alloy steels)
3	Heat treatable steels for general engineering purposes	carbon and alloy content (plain carbon & alloy steels)
4	Steel plates for boilers and pressure vessels	ultimate tensile strength and temperature (plain carbon & alloy steels)
5	Stainless steels	carbon and alloy content (alloys only)
6	Tool steels	carbon and alloy content (plain carbon & alloy steels)

Specification of steels by application in national standards

- Many national standard specifications classify steels according to properties shown such as
  - Ultimate tensile strength, or yield strength;
  - Carbon content;
  - Content of alloying elements.

GENERAL STRUCTURAL STEELS

- **Specified By Ultimate Tensile Strength**
- In many national standards, steels for general structural purposes are specified based on the minimum ultimate tensile strength required.
- **The next slide** shows standard specifications for steels for general structural purposes, according to four national standards.
- The grade specification indicates the minimum ultimate tensile strength allowed.
- For example, the material with the designation DIN 17000 St 42 is equivalent to BS 4360 Grade 43A.
- Both materials are expected to have a minimum ultimate tensile strength of 410-490 (Average of 420-430) Mpa.
- The figure 42 or 43 in the designation St 42 and 43A therefore represents 1/10 of the minimum ultimate tensile strength allowed, in Mpa.

Steels for general structural purposes

Standards Organisation and its Code				Tensile Strength UTS Mpa	Chemical Composition			
DIN[1] 1700	BS[2] 4360 Grade	ASTM[3] A283-78 Grade	JIS[4] G3101-G3125		C %	P %	S %	
St 34	-	A283 B	SS 34	330-410	<=0.17	<=0.06	<=0.05	
St 37	-	A283 B	-	360-440	<=0.17	<=0.05	<=0.05	
St 42	43A	A283 B	SM 41	410-490	<=0.25	<=0.05	<=0.05	
St 50	50C	A573Gr70	SM 50	490-590	0.25	<=0.08	<=0.05	
St 50-3	-	A633GrE	SS 33	510-610	<=0.22	<=0.45	<=0.45	
St 60	-	-	-	590-700	0.4	<=0.05	<=0.05	
St 70	-	--	-	685-830	0.5	<=0.05	<=0.05	

Steels for general structural purposes

- Steels for general structural purposes are plain carbon steels, even though carbon content is not the primary factor used in their specification.
- Steels for general structural purposes are intended to be used without further processing, for example in building structures.
- They are produced by hot rolling into shapes such as bar shapes (round, square, flat, hexagon) and structural shapes (Tee, Channel, Angle, Wide flange, Zee).

STEELS FOR GENERAL ENGINEERING PURPOSES

- **Specification By CARBON AND ALLOY CONTENT**
- Specification by carbon and alloy content is used for plain carbon and alloy steels for general engineering purposes in most national standards.
- These steels are intended for engineering purposes **other than general structural purposes**.
- The designation of the steel is then based on the carbon content such that the figure representing the carbon grade is 100 times the carbon content of the steel.
- For example, plain carbon steel with carbon content of 0.10 % would be designated as 10.

CASE HARDENING STEELS GENERAL ENGINEERING

- **Next slide** shows standard specifications for case hardening steels from four national standards.
- The table includes both plain carbon and alloy steels.
- The material designated as DIN 17210 C10, and Ck10 are equivalent to BS 970 045A10, and the materials are case hardening plain carbon steels with 0.10 % carbon content.

Case hardening steels for general engineering

Standard Organisation and its standard codes				Chemical composition					
DIN 17210	BS 970	ASTM A576 A331	JIS	C %	Cr %	Ni %	Si %	Mn %	
C10, Ck10	045A10	1010	G405L 510C	0.07-0.13			0.15-0.35	0.30-0.60	
C15, Ck15		1015	G4051 S15C	0.12-0.18			0.15-0.35	0.30-0.60	
15Cr3	523A14	5015		0.12-0.18	0.40-0.70	-	0.10-0.40	0.30-0.60	
16MnCr Ni5				0.14-0.19	0.80-1.10	-	0.15-0.40	1.00-1.30	
17Cr NiMo6	822A17			0.14-0.19	1.5-1.8	1.4-1.7	0.15-0.40	0.40-0.60	

HEAT TREATMENT OF STEELS
Non-quenching types

- These types of heat treatment are usually applied as preliminary or intermediate treatments used to condition the steel for further processing and heat treating. They include:
  - **Stress relieving**
  - This is performed to relieve stresses caused by cold working. Process consists of heating to just below the critical temperature, followed by cooling slowly, usually in air. Stresses relieved include those caused by straightening and machining.
  - **Annealing**
  - This is an intermediate process used to reduce the hardness caused by casting and forging steels above 0.35 % carbon, so that the parts may thereafter be machined. The process consists of heating the steel above the critical temperature followed by cooling slowly in a furnace.
  - **Normalising**
  - This is applied in parts that have been rolled, or forged, to refine the grain structure so that it may subsequently respond uniformly to heat treatment. The process consists of heating the steel to above the critical temperature and cooling in still air.

HEAT TREATMENT OF STEELS
Quenching Types

- Given to steel to impart the final physical properties desired for the part.
  - **Through hardening**
    - This is the most common heat treatment of steel, and involves heating the part to above the critical temperature, followed by quenching and tempering.
  - **Tempering**
    - Tempering consists of re-heating the steel to a temperature below the critical point and then cooling it at a pre-determined rate. The purpose is to reduce or draw back the as quenched hardness.
  - **Case hardening**
    - This involves hardening the surface layer of the part by the addition of carbon or nitrogen. After the addition of carbon, the part is then heated to above the critical temperature and then quenched. The purpose is to create a hard case on the part A hardened case of depth ranging from 0.25 to 2.5 mm. can be produced in this way.
  - **Surface hardening**
    - This is a form of case hardening, but in which the surface of the steel is heated directly to a point above the critical temperature and then quenched. It is usually performed on steels with a sufficiently high carbon content such as 0.30 % carbon and above. The steel is therefore able to respond to heating and quenching without the preliminary procedure of addition of carbon used in case hardening.

HEAT TREATABLE STEELS FOR GENERAL ENGINEERING

- **Specification by carbon content**
  - **Next slide** shows standard specifications for other heat treatable steels from four national standards.
  - The table includes both plain carbon and alloy steels.
  - The material designated as DIN 17200 Ck45 is equivalent to BS 970 080M46 and the materials are heat treatable plain carbon steels with 0.45-0.46 % carbon content.
- **Specification by carbon and alloying element content**
  - For alloy steels, both carbon and alloy content are used to specify the product.
  - For example, the material shown in **next slide** as DIN 17210 15Cr3, is equivalent to BS 970 523A14.
  - Both materials are expected to have a carbon content of 0.14 - 0.15 %.
  - This part of the specification is the same as that for plain carbon steels.
  - **Appendix A** shows the properties of some general engineering steel from British Standards

Heat treatable steels for general engineering

Standard Organisation and its codes				Chemical composition					
DIN 17200 17210 17211	BS 970 Part 2&3	ASTM A576 A331	JIS G4051 G4106	C %	Cr %	Ni %	Mo %	Si %	Mn %
Ck22	040A20	1020	S20C	0.18-.25	-	-	-	0.15-.35	0.30-.60
Ck35	080A35	1035	S35C	0.32-39	-	-	-	0.15-.35	0.50-.80
Ck45	080M46	1045	S45C	0.42-.50	-	-	-	0.15-.35	0.50-.80
34Cr4 34Mn4	530A36	5135	SCr435	0.30-.37	0.90-1.2	-	-	0.15-.40	0.60-.90
41Cr4	530A40	-	SCr445	0.38-.45	0.90-1.2	-	-	0.15-.40	0.50-.80
42CrMo 4	708M40	4140	SCM440	0.38-.45	0.90-1.2	-	0.15-.30	0.15-.40	0.50-.80
50CrMo 4	-	4150	SCM445	0.46-.54	0.90-1.2	-	0.15-.30	0.15-.40	0.50-.80
30CrNi Mo8	823M30	-	-	0.26-.33	1.80-2.2	1.80-2.2	0.30-.50	0.15-.40	0.30-.60

Specification by carbon and alloying element content

- To specify the content of the Chromium alloying element, the DIN standard designates the material as Cr3.
  - The figure 3 represents the alloy content multiplied by a factor of 4.
  - This means that the actual content of the Chromium alloying element is 3/4 %, or 0.75 %.
  - The material therefore is an alloy steel with:
  - Carbon content = 0.15 %
  - Chromium content = 0.75 %

Strength, Hardness and Ductility of Heat-treatable Steels

- The steels shown in Slides 11 and 14 are intended for use in machine parts.
- Carbon and alloy content, as well as heat treatment, if any, are therefore selected to achieve desired mechanical properties such as strength and hardness.
- At the same time, efforts are made to keep undesired properties such as brittleness to their minimum values.
- When selecting a starting material for a particular application, it is necessary to correlate the desired properties of strength, hardness with the carbon, alloy content and heat treatment, as well as to identify these with a particular material from a national standard .
- **Appendix A** provides guidelines for selecting material specification that will provide the desired properties of strength, hardness and ductility.

Plain carbon steels
British standard specifications

Material	British Standard[1]	Production process	Maximum section size, mm.	Yield Strength Mpa	Tensile Strength, Mpa	Elongation %	Hardness Number, HB
0.20C	070M20	HR[2]	152	215	430	22	126-179
			254	200	400	20	116-170
		CD[3]	13	385	530	12	154
			76	340	430	14	125
0.30C	080M30	HR	152	245	490	20	143-192
			254	230	460	19	134-183
		CD	13	470	600	10	174
			63	385	530	12	154
		H&T[4]	63	385	550-700	13	152-207
0.40C	080M40	HR	150	280	550	16	152-207
		CD	63	430	570	10	165
		H&T	63	385	625-775	16	179-229
0.50C	080M50	HR	150	310	620	14	179-229
		CD	63	510	650	10	188
		H&T	150	430	625-775	11	179-229

Alloy Steels
British standard specifications

1Cr	530M40	H&T	100	525	700-850	17	202-255
			29	680	850-1000	13	248-302
1.5MnMo	605M36	H&T	150	525	700-850	17	202-255
			29	755	925-1075	12	269-331
1.25NiCr	640M40	H&T	152	525	700-850	17	202-255
			102	585	770-930	15	223-277
			64	680	850-1000	13	248-302
			29	755	930-1080	12	269-331
3NiCr	653M31	H&T	64	755	930-1080	12	269-331
				680	850-1000	12	248-302
1CrMo	708M40	H&T	150	525	700-850	17	201-255
			13	940	1075-1225	12	311-375
3CrMo	722M24	H&T	152	680	850-1000	13	269-331
				755	930-1080	12	269-331
2.5NiCrMo	826M40	H&T	150	755	925-1075	12	269-331
				850	1000-1150	12	293-352
				1020	1150-1300	10	341-401

STEEL PLATES FOR BOILERS AND PRESSURE VESSELS

Specified By Ultimate Tensile Strength And Temperature

- **Next slide** shows specifications for steel plates for boilers and pressure vessels from four national standards.
- These are specified with minimum tensile strength at specified temperatures.
- These requirements are achieved by combination of low carbon and specified content of alloying elements.
- The alloy elements used are Chromium, Nickel, Molybdenum, and Manganese.

Steel plates for boilers and pressure vessels

Standard Organisation and its codes				Tensile strength UTS Mpa	Chemical composition				
DIN 17006	BS 1501 Part 1& 2	ASTM A 285 A 516 A 387	JIS G 3115 G3116 G 4109		C %	Mn %	Mo %	Cr %	Ni %
HI	141	Gr B	-	340	<=0.16	<=0.40	<=0.10	<=0.30	<=0.30
HII	Gr26C 1.1	Gr 60	5PV 24	400	<=0.20	<=0.50	<=0.10	<=0.30	<=0.30
HIII	161	Gr 65	SG 30	430	<=0.22	<=0.55	<=0.10	<=0.30	<=0.30
HIV	211			460	<=0.26	<=0.60	<=0.10	<=0.30	<=0.30
17Mn4	213			460	0.14-.20	0.90-1.2	<=0.10	<=0.30	<=0.30

STAINLESS STEELS

By Carbon And Alloy Content

- **Next slide** shows specifications for stainless steels from four national standards.
- Stainless steels have high alloy content, usually in excess of 10 % alloy.
- The alloys used are Chromium and Nickel.
- The high alloy makes the material resistant to corrosion, even at high temperature.

Stainless Steels

Standard Organisation and its codes				Chemical composition				
DIN 17440 17224	BS 970 Part 4 1479Part2	AISI 13	JIS G4303 G4309	C %	Ni %	Cr %	Si %	Mn %
X5CrNi 189	304 S15	304	SUS304	<=0.07	8.5-10.0	17.0-20.0	<=1.0	<=2.0
X12Cr NiS 188	303 S21	303	SUS 303	<=0.15	8.0-10.0	17.0-19.0	<=1.0	<=2.0

STAINLESS STEELS

- In the DIN specification, the designation is interpreted as below
  - X indicates high alloy content
  - Next number represents 1/100 of the carbon content, (12 indicates 0.12 % carbon);
  - Next Letters indicate alloying constituents;
  - Next Numbers indicate alloy content in %, CrNi188 indicates 18 % Cr and 8 % Ni..

TOOL STEELS

Carbon And Alloy Content

- **Next slide** shows specifications for Tool steels from four national standards.
- The application of tool steels includes a wide variety such as Metal cutting tools, Metal forming dies, e.t.c.
- Tool steels are therefore primarily high carbon steels in the range of 0.6 to 1.9 % carbon.
- Some tool steels are therefore plain carbon, while the majority are alloy steels.
- For example, the material designated BS 4659 BW1 (A-C) is a plain carbon steel, while BS 4659 BW2 includes a small percentage of Vanadium.
- **VANADIUM AND TUNGSTEN INCREASE THE HARDNESS**.
- Other alloys such as Chromium and Nickel modify properties such as strength, ductility toughness, and response to heat treatment,

Tool steels

Standard Organisation and its codes				Chemical composition						
VDE h Wbl 90-150 ,25 0,3 20	BS 4659	ASTM A 686 A 681 A 600	JIS G4401	C %	Cr %	Mo %	W %	V %	Si %	Mn %
C80 W1	BW1 (A-C)	W1	SK1-SK7	0.60-1.40	-	-	-	-	0.10-0.40	0.10-0.40
	BW2	W2		0.85-1.40	-	-	-	0.15-0.35	0.10-0.40	0.10-0.40
105WCr6	BO1	O1	SKS31	0.85-1.00	0.40-0.60	-	-0.40	-0.30	-0.50	1.00-1.40
90MnV8	BO2	O2		0.85-0.96	-	-	-	0.20	-0.50	1.40-2.00
60CrV7	B31	S1	SKS41	0.35-0.65	1.00-1.80	-	1.50-3.00	0.15-0.30	-0.60	-0.70
	BA2	A2	SKD12	0.95-1.05	4.75-5.50	0.90-1.40	-	0.15-0.50	-0.40	-1.0
X165CrMoV12	BD2	D2		1.4-1.9	11-13	0.6-1.2	-	-1.10	-0.60	-0.60
X38CrMoV51	BH	H11	SKD6	0.32-0.42	4.75-5.25	1.00-1.50	-	0.30	0.85-1.1	-0.50

Material selection: Example - KSB Etanorm Pump Series

PART	Material used for each part in each pump designation				
	Etanorm G	Etanorm M	Etanorm B	Etanorm S	Etanorm C
Volute casing	Grey cast iron GG-25	Grey cast iron GG-25	Tin Bronze G-CuSn10	Nodular cast iron GGG-40.3	Cast Chrome Nickel Molybdenum steel 1.4408
Discharge cover	Grey cast iron GG-25	Grey cast iron GG-25	Tin Bronze G-CuSn10	Nodular cast iron GGG-40.3	Cast Chrome Nickel Molybdenum steel 1.4408
Impeller	Grey cast iron GG-25	Tin Bronze G-CuSn10	Tin Bronze G-CuSn10	Grey cast iron GG-25	Cast Chrome Nickel Molybdenum steel 1.4408
Casing wear rings	Grey cast iron GG	Grey cast iron GG /Red Bronze G-CuPb10Sn	Red Bronze G-CuPb10Sn	Grey cast iron GG	Chrome Nickel Molybdenum steel 1.4408
Shaft	Tempering steel St 60/45	Tempering steel St 60/45	Chrome Nickel Molybdenum steel 1.4462	Tempering steel St 60/45	Cast Chrome Nickel Molybdenum steel 1.4462
Shaft sleeve	Chrome Nickel Molybdenum steel 1.4571	Chrome Nickel Molybdenum steel 1.4571	Chrome Nickel Molybdenum steel 1.4571	Chrome Nickel Molybdenum steel 1.4571	Chrome Nickel Molybdenum steel 1.4571
Shaft protecting sleeve	Chrome Molybdenum steel 1.4122	Chrome Molybdenum steel 1.4122	Chrome Nickel Molybdenum steel 1.4571	Chrome Molybdenum steel 1.4122	Chrome Nickel Molybdenum steel 1.4571
Bearing bracket	Grey cast iron GG-25	Grey cast iron GG-25	Grey cast iron GG-25	Grey cast iron GG-25	Grey cast iron GG-25