Mechanical Properties of Steel Bolts, Screws and Studs

1. Basic Concepts

1.1 Metals used in fastener manufacture are elastic materials which will stretch (elongate) under applied loads and return to their original shape when the load is removed. However, if sufficient load is applied, the material will stretch beyond its yield point and enter a plastic zone, losing its elasticity and becoming permanently stretched. Further increased load on the material will stretch it to its ultimate tensile strength at which point the material will fracture.

1.2 The major factor in determining the load a material can carry is its tensile strength, which is related to its hardness. The terms used to describe the strength and load bearing properties of a metal fastener are:

Tensile Strength – is an expression of the maximum capacity of a particular material to stretch under tension load prior to failure.

Yield Stress (Yield Point) – is an expression of the theoretical point of stress (pressure) beyond which the material loses its elasticity and becomes permanently stretched (realistically, a range rather than a single point).

Proof Load Stress – is an expression of the minimum stress a material must achieve, prior to permanent elongation and, the stress which would be applied to test and remeasure a specific fastener to prove it had not permanently stretched and that it will carry the required load. These terms will also include a unit of area, are approximately between 80% and 90% of the theoretical yield stress and are expressed in the same terms. Proof load stresses also apply to nuts and are the point at which the nut is deemed to have failed.

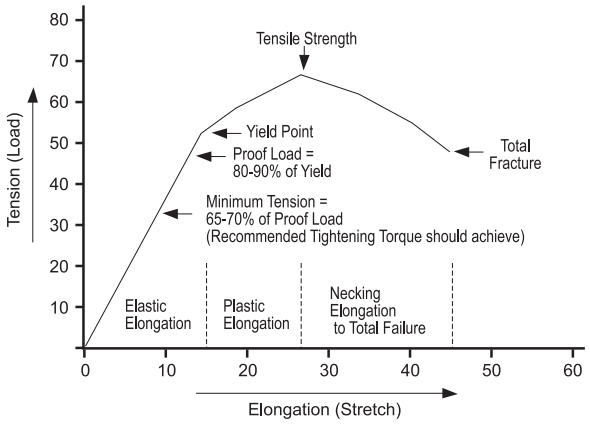
Ultimate Tensile Stress – is the theoretical minimum point at which the material will fracture. It is expressed in the same terms as yield stress and proof load stress. These properties are used to calculate the proof load and breaking load for each diameter of each grade or class of product.

1.3 Bolt Tensioning

The following chart pictorially demonstrates the typical tension/elongation relationship, the various zones of elongation and points of tension.

- Elastic Elongation: elongation from which the fastener will recover when load is removed.
- Plastic Elongation: elongation which is permanent and renders the fastener non-reusable.
- Necking Elongation: elongation past the tensile strength of the fastener from where the diameter is reducing, the tension is decreasing and fracture results.
- Minimum Tension: the minimum tension used for design purposes = 65-70% of proof load and is the theoretical minimum tension the recommended tightening torque should achieve.
- Proof Load: the minimum point prior to permanent elongation and the test point for actual proof load testing.
- Yield Point: the point at which elasticity is lost and permanent elongation commences.
- Tensile Strength: the maximum load-carrying point prior to fracture.

Typical Tension / Elongation Chart



2. Designation of Property Classes

2.1 The property classes and their mechanical properties apply to bolts, screws and studs, with metric (ISO) thread, with nominal thread diameter d ≤ 39mm, made of carbon steel or alloy steel and when tested at room temperature.

2.2 The property class symbols, indicating the most important mechanical properties, consist of two figures, one on either side of a dot. For example, 8.8, the first figure indicates 1/100 of the nominal tensile strength in N/mm^2. (See $R_{m,nom}$ in the table of next page) So property class 8.8 has a tensile strength of 8 x 100 = 800 N/mm^2. The second figure indicates 10 times the ratio between lower yield stress R_{eL} (or proof stress $R_{p0.2}$) and nominal tensile strength $R_{m,\,nom}$ (yield stress ratio). So at property class 8.8 the second figure 8 = 10 x 800/1000. The multiplication of these two figures will give 1/10 of the yield stress in N/mm^2, so 8 x 8 = 1/10 x 640 N/mm^2.

3. Mechanical and Physical Properties of Steel Bolts, Screws and Studs in accordance with ISO898-1:1999 is given below:

Sub-clause number	Mechanical and physical property			Property class										
				3.6	4.6	4.8	5.6	5.8	6.8	8.8[a] d ≤ 16[c] mm	8.8[a] d > 16[c] mm	9.8[b]	10.9	12.9
5.1	Nominal tensile strength, $R_{m,\,nom}$		N/mm²	300	400		500		600	800	800	900	1000	1200
5.2	Minimum tensile strength, $R_{m,\,min}$ [d e]		N/mm²	330	400	420	500	520	600	800	830	900	1040	1220
5.3	Vickers hardness, HV		min.	95	120	130	155	160	190	250	255	290	320	385
	F ≥ 98N		max.	220[f]					250	320	335	360	380	435
5.4	Brinell hardness, HB		min.	90	114	124	147	152	181	238	242	276	304	366
	$F = 30\ D^2$		max.	209[f]					238	304	318	342	361	414
5.5	Rockwell hardness, HR	min.	HRB	52	67	71	79	82	89	-	-	-	-	-
			HRC	-	-	-	-	-	-	22	23	28	32	39
		max.	HRB	95.0[f]					99.5	-	-	-	-	-
			HRC	-					-	32	34	37	39	44
5.6	Surface hardness, HV 0.3		max.	-						[g]				
5.7	Lower yield stress,		nom.	180	240	320	300	400	480	-	-	-	-	-
	R_{eL}[h], N/mm²		min.	190	240	340	300	420	480	-	-	-	-	-
5.8	Stress at 0.2% non-proportional		nom.	-					-	640	640	720	900	1080
	elongation $R_{p0.2}$[i], N/mm²		min.	-					-	640	660	720	940	1100
5.9	Stress under proof load, S_p	S_p/R_{eL} or $S_p/R_{p0.2}$		0.94	0.94	0.91	0.93	0.90	0.92	0.91	0.91	0.90	0.88	0.88
			N/mm²	180	225	310	280	380	440	580	600	650	830	970
5.10	Breaking torque, M_B		Nm min.	-						See ISO 898-7				
5.11	Percent elongation after fracture, A		min.	25	22	-	20	-	-	12	12	10	9	8
5.12	Reduction area after fracture, Z		% min.	-						52		48	48	44
5.13	Strength under wedge loading[e]			The values for full size bolts and screws (no studs) shall not be smaller than the minimum values for tensile strength shown in 5.2										
5.14	Impact strength, KU		J min.	-			25	-		30	30	25	20	15
5.15	Head soundness			No fracture										
5.16	Minimum height of non-decarburized thread zone, E			-						$\frac{1}{2}H_1$			$\frac{2}{3}H_1$	$\frac{3}{4}H_1$
	Maximum depth of complete decarburization, G		mm	-						0.015				
5.17	Hardness after retempering			-						Reduction of hardness 20 HV maximum				
5.18	Surface integrity			In accordance with ISO 6157-1 or ISO 6157-3 as appropriate										

[a] For bolts of property class 8.8 in diameters d ≤16 mm, there is an increased risk of nut stripping in the case of inadvertent over-tightening inducing a load in excess of proof load. Reference to ISO 898-2 is recommended.

[b] Applies only to nominal thread diameters d ≤ 16 mm.

[c] For structural bolting the limit is 12 mm.

[d] Minimum tensile properties apply to products of nominal length l ≥ 2.5 d. Minimum hardness applies to products of length l < 2.5 d and other products which cannot be tensile-tested (e.g. due to head configuration).

[e] When testing full-size bolts, screws and studs, the tensile loads, which are to be applied for the calculation of R_m, shall meet the values given in Table 6 and Table 8.

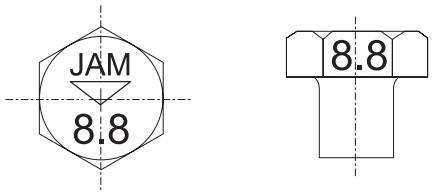
[f] A hardness reading taken at the end of bolts, screws and studs shall be 250 HV, 238 HB or 99.5 HRB maximum.

[g] Surface hardness shall not be more than 30 Vickers points above the measured core hardness on the product when readings of both surface and core are carried out at HV 0.3. For property class 10.9, any increase in hardness at the surface which indicates that the surface hardness exceeds 390 HV is not acceptable.

[h] In cases where the lower yield stress R_{eL} cannot be determined, it is permissible to measure the stress at 0.2% non-proportional elongation $R_{p0.2}$. For the property classes 4.8, 5.8 and 6.8 the values for R_{eL} are given for calculation purposes only, they are not test values.

[i] The yield stress ratio according to the designation of the property class and the minimum stress at 0.2% non-proportional elongation $R_{p0.2}$ apply to machined test specimens. These values if received from tests of full size bolts and screws will vary because of processing method and size effects.

4. Marking of Bolts, Screws and Studs



- Marking of all property classes is obligatory for hexagon bolts and screws with nominal diameters d ≥ 5mm, preferably on top of the head.
- Studs shall be marked for property classes ≥ 8.8 and with nominal diameter ≥ 5mm. For studs with interference fit, the marking shall be at the nut end.
- The trade (identification) marking of the manufacturer is mandatory on all products which are marked with property classes.
- For other types of bolts and screws the same marking system shall be used. For special components marking will be as agreed between the interested parties.

Mechanical Properties of Steel Nuts

1. The property classes and their mechanical properties mentioned below apply to nuts with metric ISO thread with nominal thread diameters up to and including 39mm, and heights not less than 0.8D (including the normal countersunk on the thread), made of carbon steel or low alloy steel and when tested at room temperature.

   It does not apply to nuts which have to meet special requirements, such as for weldability, corrosion resistance, ability to withstand temperatures above + 300°C or below -50°C or locking. Nuts made from free-cutting steel shall not be used above +250°C. There is an increased risk of stripping for assemblies with threads having wider tolerances. The use for nuts above 39mm is only permitted, when the nuts meet all the requirements.

2. Designation of Property Classes

The symbol for property classes consists of a figure that indicates 1/100 of the proof load stress in N/mm².

E.g. class 8 has a proof load stress of 8 x 100 = 800 N/mm². This proof load stress is equal to the minimum tensile strength of a bolt, which can be loaded up to the minimum yield strength of the bolt when mated with the nut concerned.

Nuts of a higher property class can generally be used in the place of nuts of a lower class.

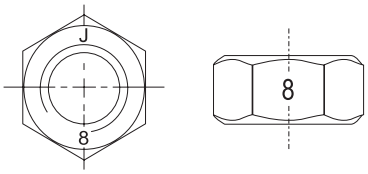
3. Mechanical Properties of Steel Nuts in accordance with BS3692:2001 is given below:

Strength grade designation	4	5	6	8	10	12	
Proof load stress[a] N/mm²	400	500	600	800	1000	1200	[c]
Brinell hardness (HB) max.	302	302	302	302	353	375	All nuts
Rockwell hardness[b] (HRC) max.	30	30	30	30	36	39	All nuts
Vickers hardness (HV) max.	310	310	310	310	370	395	All nuts

NOTE For Materials and Mechanical Properties of hexagon bolts and screws, refer to BS EN ISO 898-1.

[a] The proof load is calculated by multiplying the proof load stress by the tensile stress area of the bolt.
[b] The conversion from Brinell hardness into Rockwell hardness has been calculated according to BS EN ISO 6506-1,2 and 3 and BS EN 10109-1.
[c] All nuts other than those exempted by agreement between the purchaser and the manufacturer. Nuts with a specified proof load in excess of 500 000 N (see Table 10) may be exempt from proof load testing. Such nuts shall meet the minimum hardness as agreed between the purchaser and the manufacturer.

4. Marking of Nuts



Hexagon nuts ≥ M5 shall be marked with the symbol of the property class, and the trade (identification) marking of the manufacturer on the bearing surface or side.