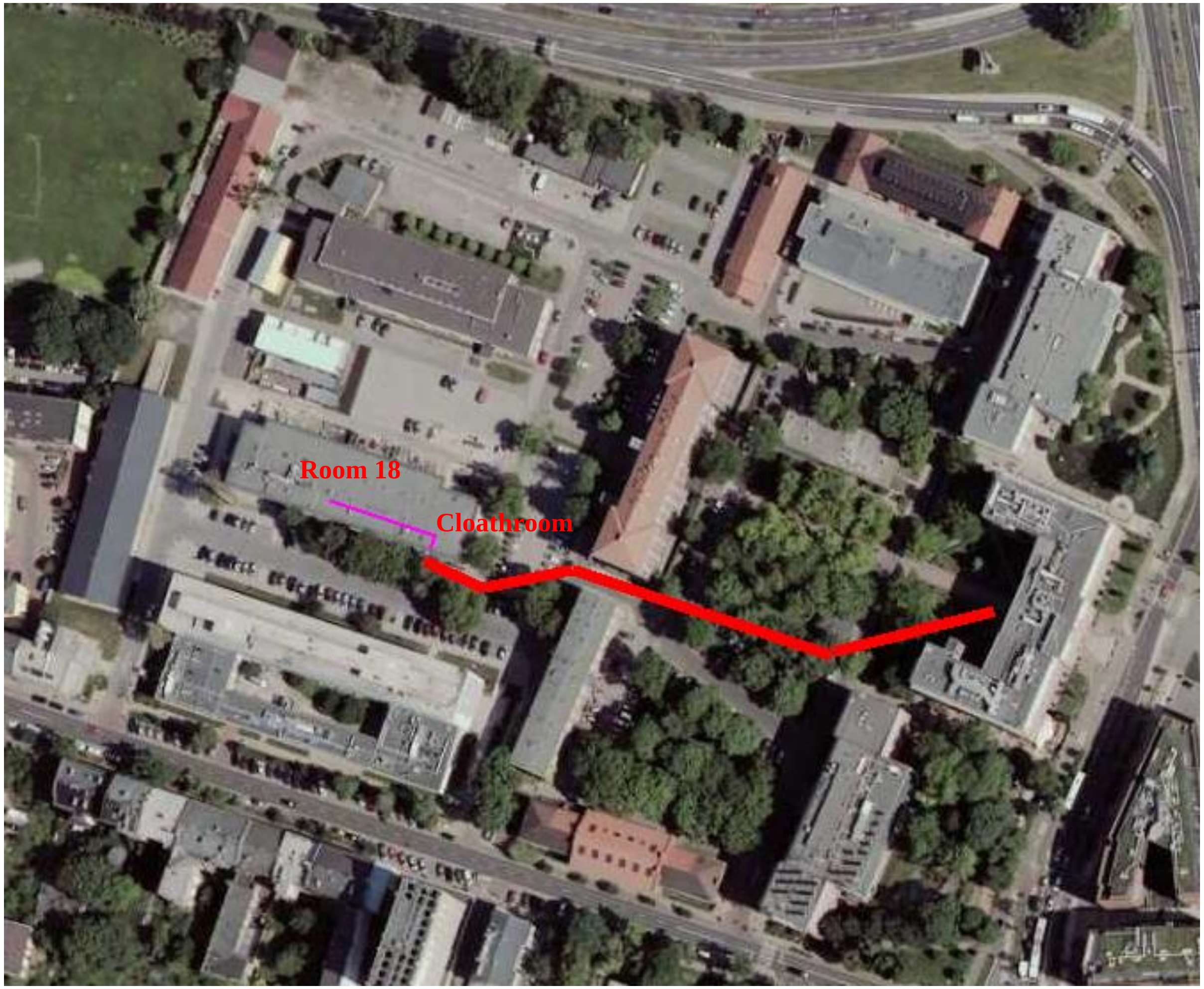
Metal Structures

Laboratory III, IV

Testing of mechanical parameters

Attention

Next laboratory will be held in building 10-29, room 18, ground level.



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Please come in groups of not more than 12 people. It is best to follow the division into dean groups.

Cloathroom is obligatory.

LABORATORY OBJECTIVE'S

Importance of mechanical tests (Universal Testing Machine, Brinell hardness, Cauchy hammer);

Statistical analysis of UTS results;

1. Elaborate a protocol of static tensile steel test. Analyze mechanical properties.

2. Elaborate a protocol of static tensile aluminum test.

3. Elaborate a protocol of Brinell hardness test. Based on the result, identify the grade of steel.

4. Elaborate a protocol of Charpy impact test hammer Based on the result, identify the subgrade of steel.

5. Basing on values of strength steel specimens, obtained at universal testing machine, calculate design value of yield strength.

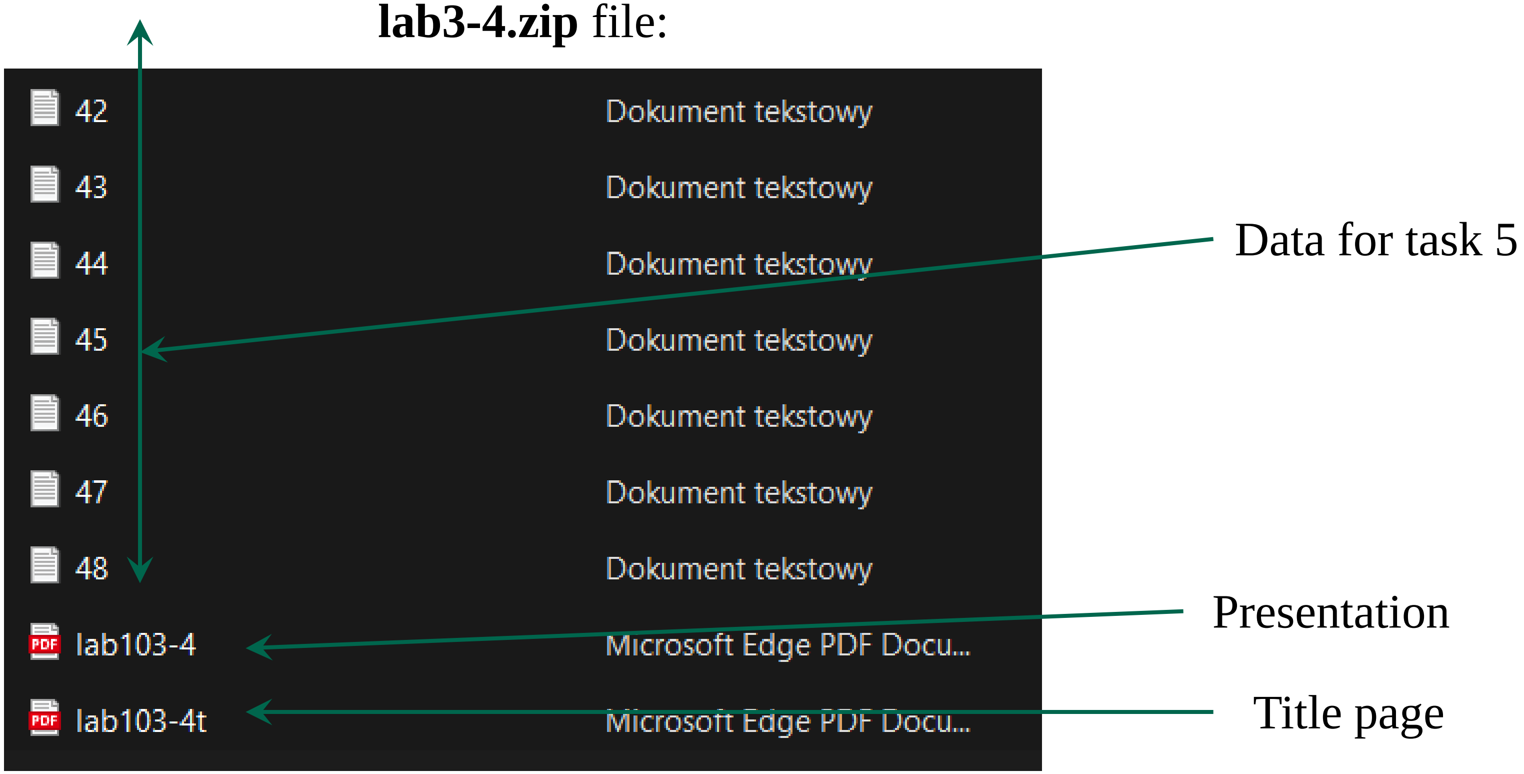
Two separated grades:

- For points 1+2+3+4 → $L_{3\text{-}4,\ 2}$
- For point 5 → $L_{3\text{-}4,\ 1}$

Task 5: Statistic of results

Number of results from UTM will be too small to make full statistic. You will make statistical analysis, based on data attachet to presentation (files 01.txt - 48.txt)

lab3-4.zip file:



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Example of data [MPa]:

294,8	268,9	255,6	255,9	279,2	298,8	253,9	284,5	271,0	284,3
288,6	265,3	276,6	278,1	312,0	301,5	245,1	318,9	288,0	237,7
280,0	302,0	258,2	289,8	249,3	280,5	249,4	305,5	259,0	283,1
294,3	262,5	229,2	262,1	231,2	264,1	256,7	271,8	274,1	265,3
277,7	310,5	282,0	277,3	247,2	307,8	268,2	275,5	286,6	311,5
252,6	288,0	326,3	276,5	247,5	310,9	275,6	300,4	282,0	274,8

$n = 60$ results

According to information from Lecture #2:

$(R_1, R_2, R_3 \dots R_{30}) = (264,3 \; ; \; 320,4 \; ; \; 241,4 \; \dots 318,8)$

Change the order of the results:

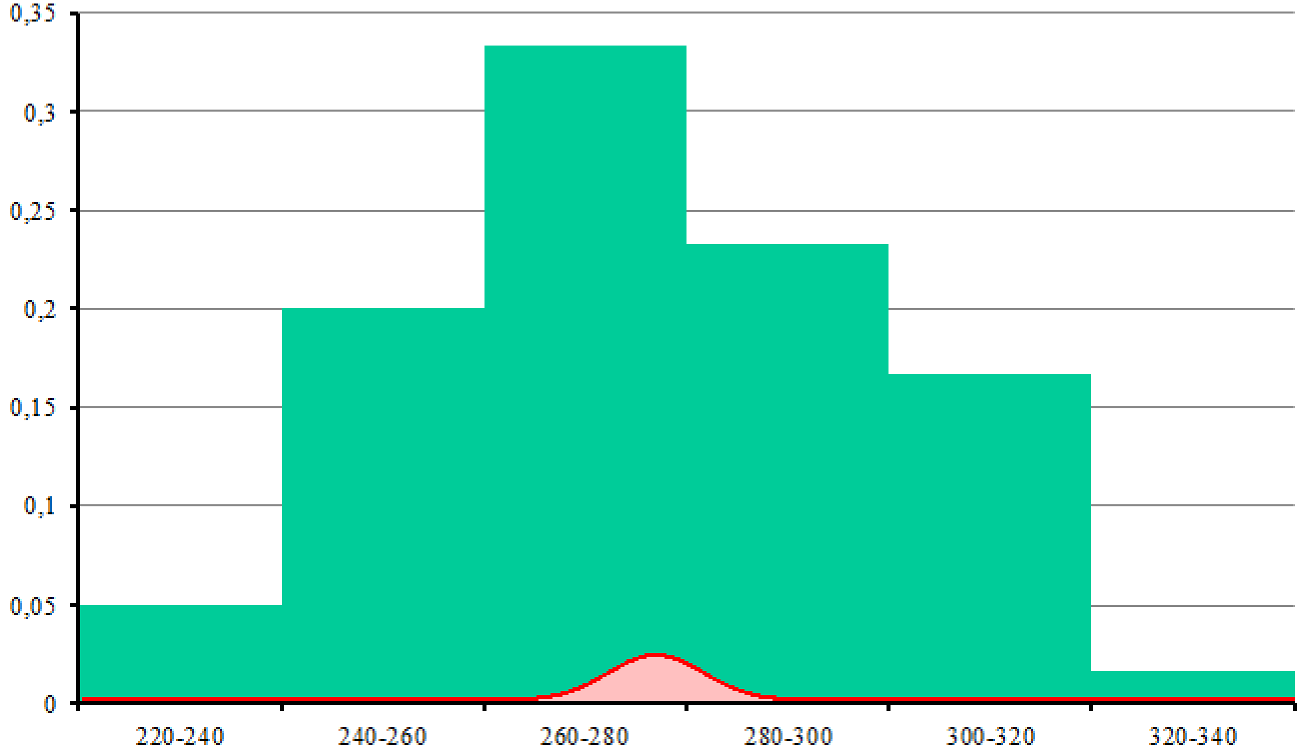
$R_{min} \leq R_a \leq R_b \leq R_c \leq \dots \leq R_{max}$

229,2	231,2	237,7	245,1	247,2	247,5	249,3	249,4	252,6	253,9
255,6	255,9	256,7	258,2	259,0	262,1	262,5	264,1	265,3	265,3
268,2	268,9	271,0	271,8	274,1	274,8	275,5	275,6	276,5	276,6
277,3	277,7	278,1	279,2	280,0	280,5	282,0	282,0	283,1	284,3
284,5	286,6	288,0	288,0	288,6	289,8	294,3	294,8	298,8	300,4
301,5	302,0	305,5	307,8	310,5	310,9	311,5	312,0	318,9	326,3

$R_{min} = 229,2$ MPa

$R_{max} = 326,3$ MPa

Limits [MPa] (Δ_R = 20 MPa)	220-240	240-260	260-280	280-300	300-320	320-340
Number of results	3	12	20	14	10	1



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This type of results we can described by a normal distribution $\phi(x)$:

$$\phi(x) = \frac{1}{\sigma_{Re}\sqrt{2\pi}} \exp\left(-\frac{(x-\mu_{Re})^2}{2\sigma_{Re}^2}\right)$$

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$$x = R_{e,i}$$

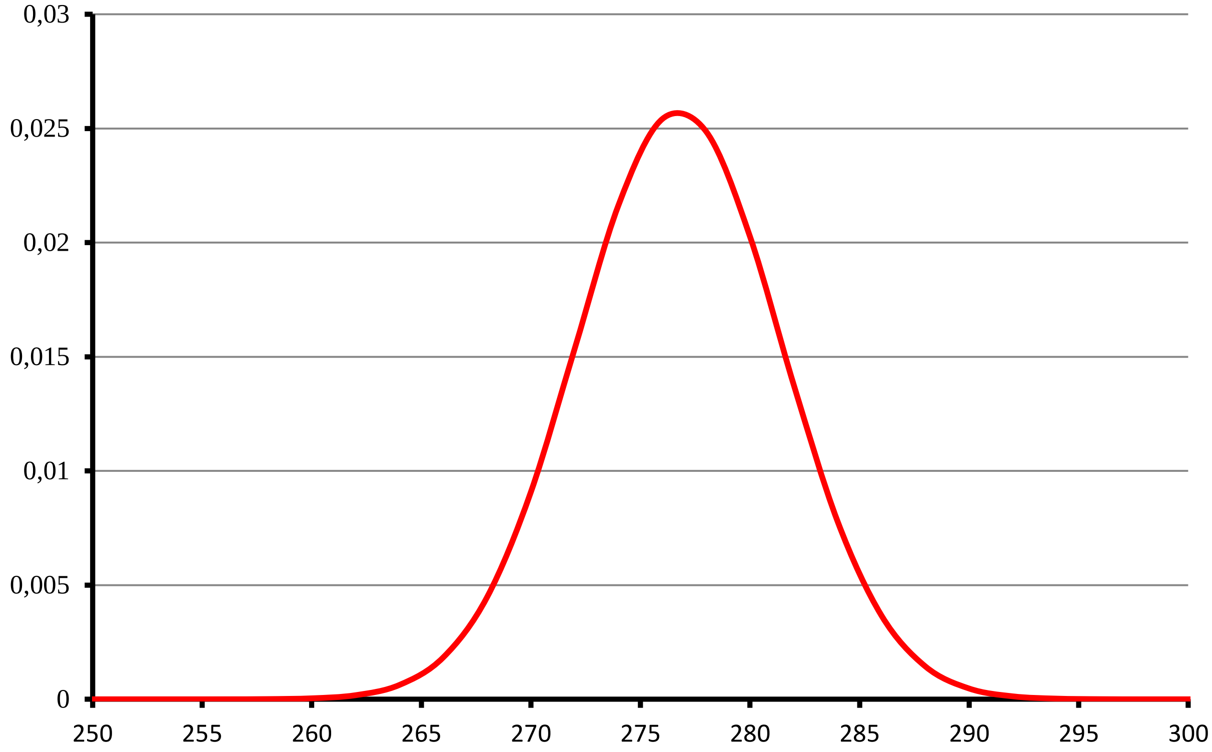
$$\mu_{Re} = (\Sigma R_{e,i}) / n \quad \text{(average)}$$

$$\sigma_{Re} = \sqrt{\{[\Sigma (R_{e,i} - \mu_{Re})^2] / n\}} \quad \text{(standard deviation)}$$

The same way of recalculations for R_m

$$\mu_{Re} = 276{,}8\ \text{MPa}$$

$$\sigma_{Re} = 21{,}9\ \text{MPa}$$



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According to information from Lecture #2:

$$f_{y,\,k} = \text{lower quantile } 5\% \text{ of } R_e$$

$$f_{y,\,d} = f_{y,\,k} / \gamma_M$$

Value of quantiles can be calculated in dependence to μ_{Re} and σ_{Re}.

<u>Quantile</u>: such strength value, that smaller values occur only for certain % of samples

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Below 240 MPa: 5% results

Below 260 MPa: 25% results

Below 280 MPa: 58% results

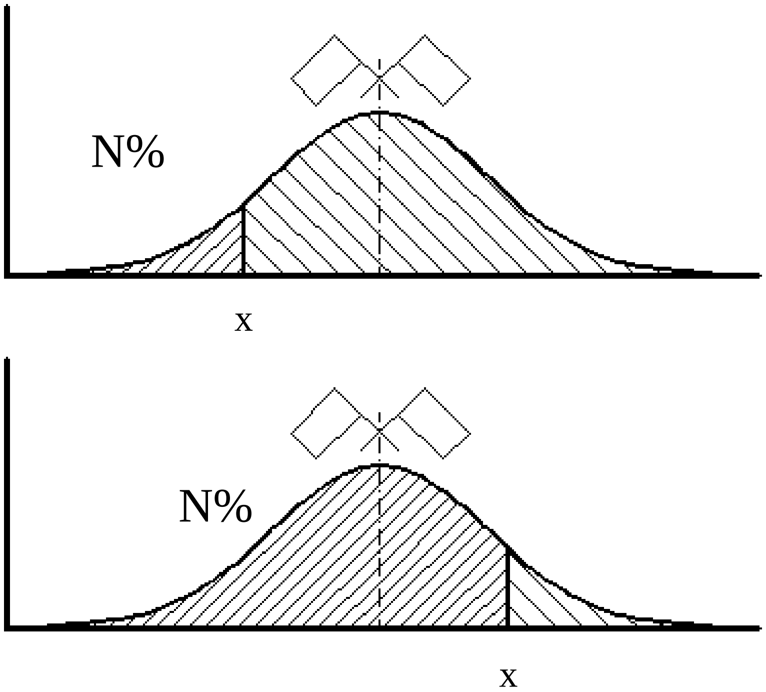
240 MPa → 5% quantile

260 MPa → 25% quantile

Average (276,8 MPa) → 50% quantile

280 MPa → 58% quantile

Calculation of quantile is much more accurate, when we base on normal distribution, not bar diagram:



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Value x is N% quantile, when:

$$N\%\ \text{of total area} = \int_{-\infty}^{x} \phi(\xi)\, d\xi$$

Area under curve on left side of x.

(There is dξ no dx to avoit of symbols conflict)

We analysed this problem as function for curve and area under curve.

But, generally, there are special definitions in maths for this problem:

$\phi(x)$ - distribution (here: normal distribution)

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$$\Phi(x) = \int_{-\infty}^{x} \phi(\xi)\, d\xi$$ - cumulative distribution

$$d / dx\, [\Phi(x)] = \Phi(x)' = \phi(x)$$

We can draw curve for $\phi(x)$, and, of course, we can draw curve for $\Phi(x)$.

In analysed case, area under line and cumulative distribution is the same object:

$$N\% = A(x) = \int_{-\infty}^{x} \phi(\xi)\, d\xi = \Phi(x)$$

$$0{,}0 \le \Phi(x) \le 1{,}0$$

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Relation $\Phi(x) = \int_{-\infty}^{x} \phi(\xi)\, d\xi$ can be analised:

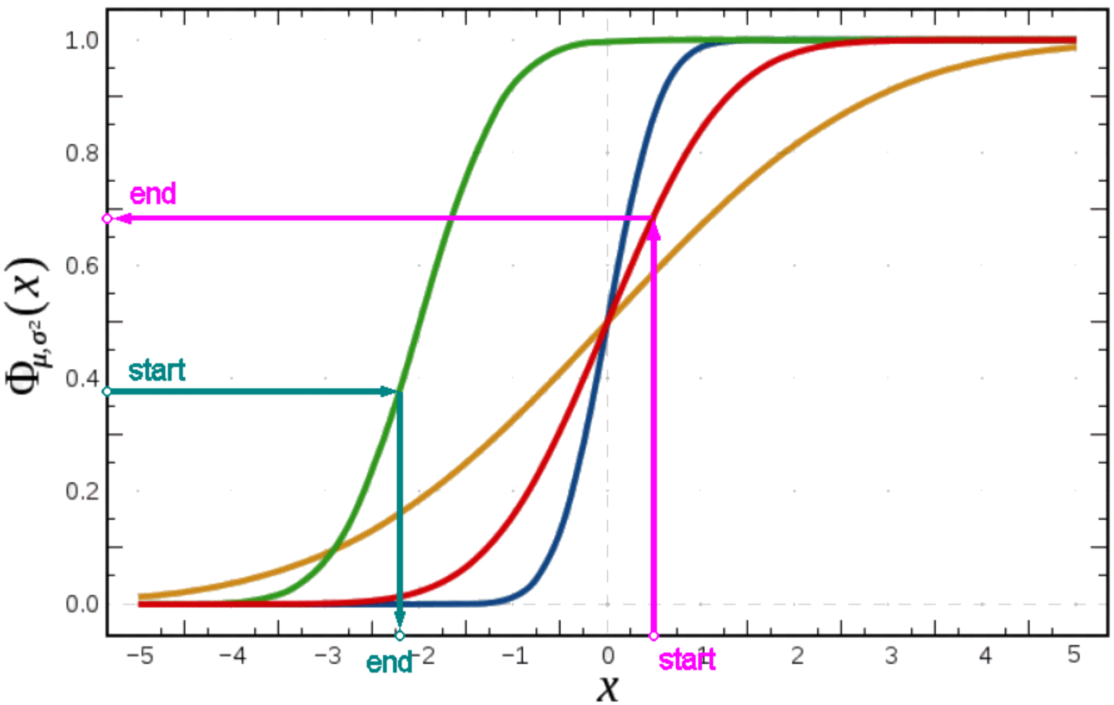
- from x to $\Phi(x)$ (calculation of function);
- from F(x) to x (calculation of inverse of function $[F(x)]^{[-1]}$);

For example:

$$\Phi(x) = x^2 \quad ; \quad x = 5 \rightarrow \Phi(x) = 5^2 = 25$$

$$x = [\Phi(x)]^{[-1]} = \sqrt{[\Phi(x)]} \quad ; \quad \Phi(x) = 49 \rightarrow x = \sqrt{49} = 7$$

- data: x ; finding value: **Φ** = N%
- data: **Φ** = N% ; finding value: x



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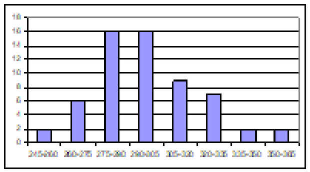
First case is calculation of cumulative distribution.

Second case is finding value of quantile.

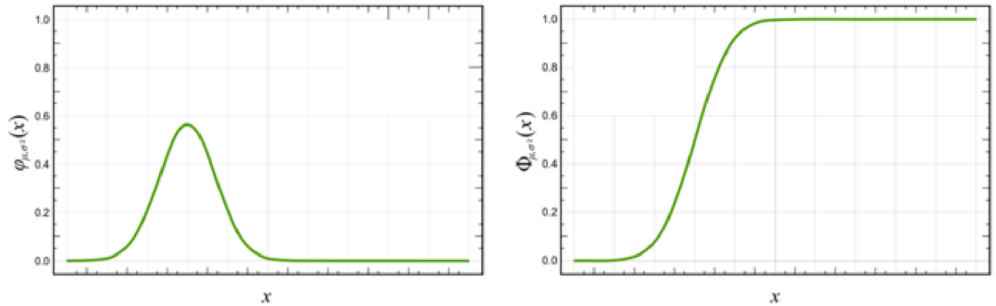
Algorithm:

Test in Universal Testing Machine



μ_{Re} , σ_{Re}

Normal Distribution (μ_{Re} , σ_{Re})



Cumulative Distribution (μ_{Re} , σ_{Re})

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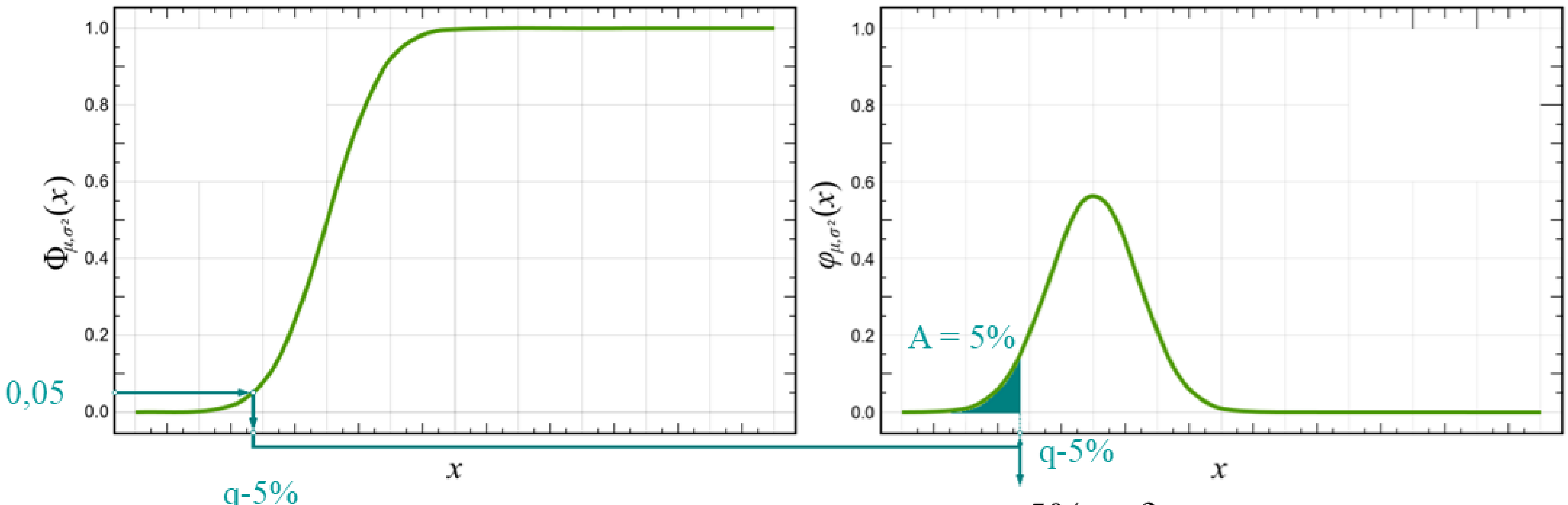
Cumulative Distribution (μ_{Re} , σ_{Re})

Normal Distribution (μ_{Re} , σ_{Re})



q-5% = f_k

Name	Formulas	
	Distribution	Cumulative distribution
Normal (Gauss)	$\frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$	$\frac{1}{2}\left(1+\operatorname{erf}\frac{x-\mu}{\sigma\sqrt{2}}\right)$
Log-normal	$\frac{1}{\sqrt{2\pi}\sigma x} \exp\left(-\frac{(\ln x-\mu)^2}{2\sigma^2}\right) \cdot \mathbf{1}_{(0,\infty)}$	$\frac{1}{2}+\frac{1}{2}\operatorname{erf}\left[\frac{\ln(x)-\mu}{\sigma\sqrt{2}}\right]$
Weibull	$(k/\lambda)(x/\lambda)^{(k-1)}e^{-(x/\lambda)^k}$	$1-e^{-(x/\lambda)^k}$
Fréchet (λ = 0,0 ; β = 1,0)	$\frac{z\exp(-z)}{\beta}$ $\quad z=\exp\left[-\frac{x-\lambda}{\beta}\right]$	$\exp(-\exp[-(x-\lambda)/\beta])$
Gumbel	$\frac{1}{\beta}e^{-(z+e^{-z})}$ $\quad z=\frac{x-\mu}{\beta}$	$e^{-e^{-(x-\mu)/\beta}}$

Two symbols are used in table on previous page: **exp** for distribution and **erf** for cumulative distribution. The meaning of these symbols is as follow:

$$\exp(\xi) = e^{\xi} \quad ; \quad \text{for normal distribution: } \xi = (x - \mu)^2 / (2\,\sigma^2)$$

$$\text{erf}(t) = {}_{-\infty}\int^{t} [\exp(\xi^2)\, d\xi] \quad ; \quad \text{for cumulative distribution of normal distribution:}$$

$$\xi = (x - \mu) / (2\,\sigma^2)$$

ξ is <u>normalized variable</u>, this means $\xi_{average} = 0$

erf(t) is a **non-elementary function**. It can be **solved numerically only**. **The same applies to the inverse of this function**.

The results are often presented in special tables.

Example of table for normal distribution and cumulative normal distribution

Funkcje odwrotne *Laplace'a* Φ^{-1} i *Millsa* ϕ^{-1}

$$t = \Phi^{-1}\left(\frac{1}{n}\right), \quad \text{jeśli } \Phi(t) = \frac{1}{n}, \qquad t = \phi^{-1}\left(\frac{1}{k}\right), \quad \text{jeśli } \phi(t) = \frac{1}{k}$$

$1/n$ $1/k$	$\Phi^{-1}\left(\frac{1}{n}\right)$	$\phi^{-1}\left(\frac{1}{k}\right)$	$1/n$ $1/k$	$\Phi^{-1}\left(\frac{1}{n}\right)$	$\phi^{-1}\left(\frac{1}{k}\right)$
10^{-12}	−7,0340	7,3092	0,01	−2,3269	2,7164
10^{-11}	−6,7056	6,9871	0,02	−2,0542	2,4496
10^{-10}	−6,3609	6,6493	0,03	−1,8812	2,2799
10^{-9}	−5,9974	6,2935	0,04	−1,7511	2,1521
10^{-8}	−5,6117	5,9164	0,05	−1,6452	2,0481
10^{-7}	−5,1991	5,5135	0,06	−1,5551	1,9596
10^{-6}	−4,7533	5,0787	0,07	−1,4761	1,8819
$5 \cdot 10^{-6}$	−4,4171	4,7512	0,08	−1,4053	1,8124
10^{-5}	−4,2648	4,6030	0,09	−1,3410	1,7493
$5 \cdot 10^{-5}$	−3,8906	4,2390	0,10	−1,2817	1,6912
10^{-4}	−3,7191	4,0722	0,20	−0,8415	1,2743
$5 \cdot 10^{-4}$	−3,2900	3,6557	0,30	−0,5240	0,9670
10^{-3}	−3,0905	3,4609	0,40	−0,2529	0,7262
$5 \cdot 10^{-3}$	−2,5762	2,9600	0,50	0,0000	0,5179

J. Murzewski, „Niezawodność konstrukcji inżynierskich", Arkady Warszawa 1989

Calculation of quantile

Tables are dedicated for normalised variables:

$$\boldsymbol{\xi^2 = (x - \mu)^2 / (\sigma^2)}$$

normalised $q_{N\%} = (q_{N\%} - \mu) / \sigma$

Φ (normalised $q_{N\%}$) = N% = N / 100

$$\Phi\,[(q_{N\%} - \mu) / \sigma] = N / 100$$

$(q_{N\%} - \mu) / \sigma = [\Phi\,(N / 100)]^{(-1)}$ ⇦ inversion of both sides of equation

$$q_{N\%} - \mu = \sigma\,[\Phi\,(N / 100)]^{(-1)}$$

$$\boldsymbol{q_{N\%} = \mu + \sigma\,[\Phi\,(N / 100)]^{(-1)}}$$

$N = 5\% = 0{,}05 \rightarrow$ table #t / 20 $\rightarrow [\Phi(0{,}05)]^{(-1)} = -1{,}645$

$$q_{5\%,\,norm} = \mu + \sigma\,[\Phi(0{,}05)]^{(-1)} = \boldsymbol{\mu - 1{,}645\,\sigma}$$

$1/n$ $1/k$	$\Phi^{-1}\left(\frac{1}{n}\right)$	$\phi^{-1}\left(\frac{1}{k}\right)$
0,01	−2,3269	2,7164
0,02	−2,0542	2,4496
0,03	−1,8812	2,2799
0,04	−1,7511	2,1521
0,05	−1,6452	2,0481
0,06	−1,5551	1,9596
0,07	−1,4761	1,8819

J. Murzewski, „Niezawodność konstrukcji inżynierskich", Arkady Warszawa 1989

For our example:

$\mu = 276{,}8$ MPa

$\sigma = 21{,}9$ MPa

$q_{5\%,\,norm} = 276{,}8 - 1{,}645 \cdot 21{,}9 = 240{,}8$ MPa

Probably steel S235

Characteristic and designing values:

$f_{y,\,k} = q_{5\%,\,norm}$

$f_{y,\,d} = f_{y,\,k} / \gamma_M$

$\gamma_M = 1{,}0$

$f_{y,\,d} = 240{,}8$ MPa

Most calculations in point 5 (without introductory explanations) fit into a few lines

Universal testing machine

EN 10 002-1

Photo: Author

Photo: feiplar.com.br

The results for structural steel, alumnium and special steel (non-structural steel):

Wyniki badania:

Legenda	Nr	L_0 mm	S_0 mm^2	$R_{p0.2}$ MPa	R_{eH} MPa	R_{eL} MPa	R_m MPa	R_B MPa	F_m kN	A_{gt} %	Z %
	6	100,40	78,54	-	-	-	244	161	19,14	8,68	-
	7	120,28	113,10	-	354	342	459	287	51,95	26,61	-
	8	120,19	113,10	-	-	-	702	415	79,43	6,15	-

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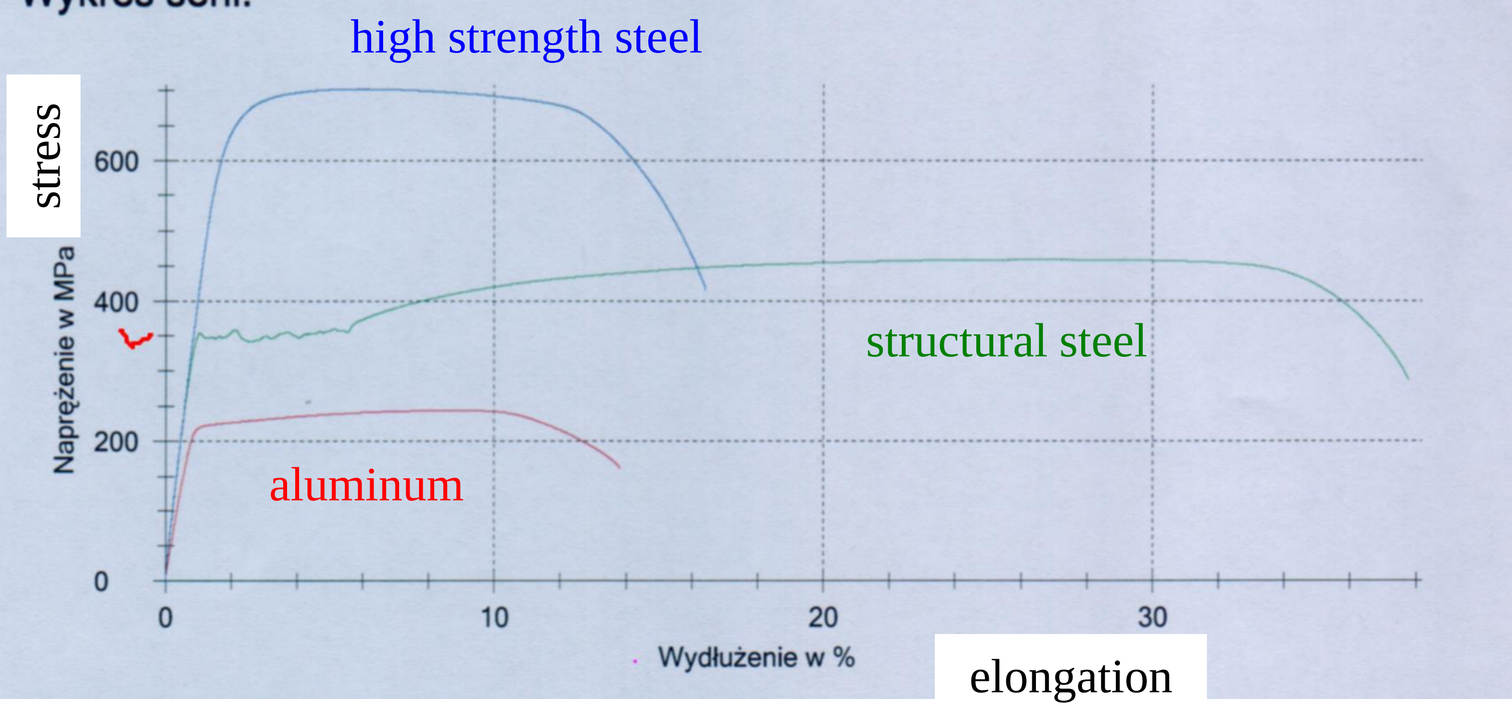
Wykres serii:



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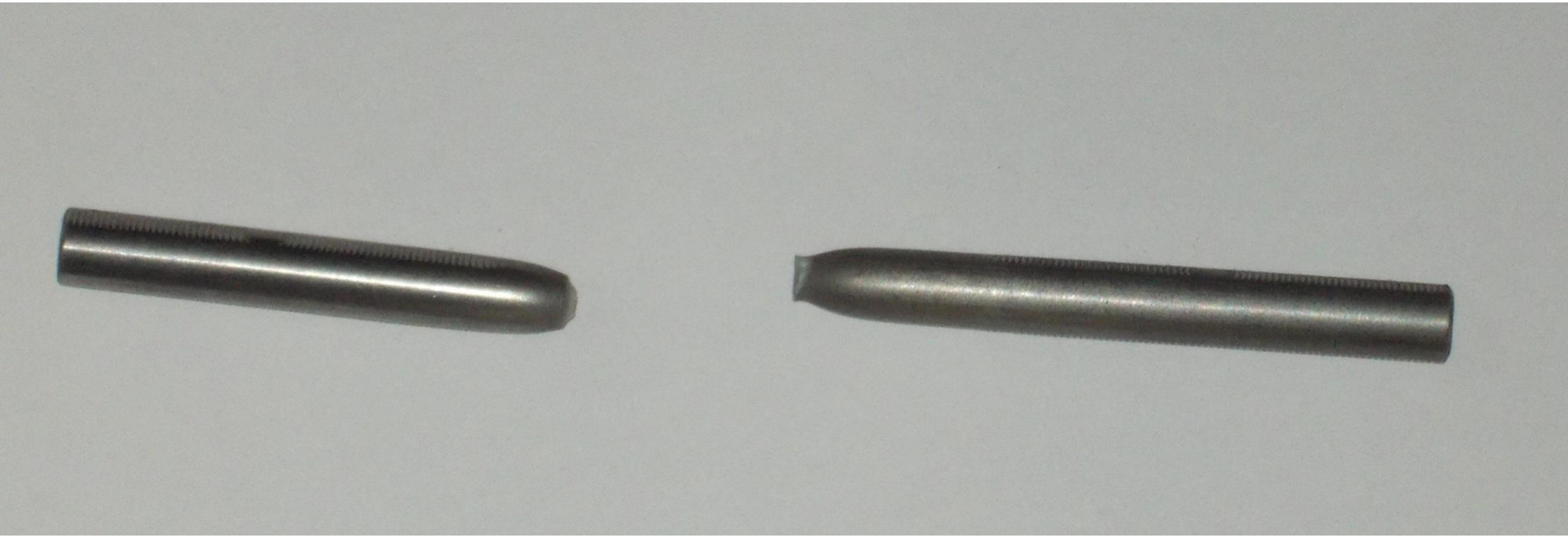
Speciment after testing - tension



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(informal speciment, A = const)

Summation:

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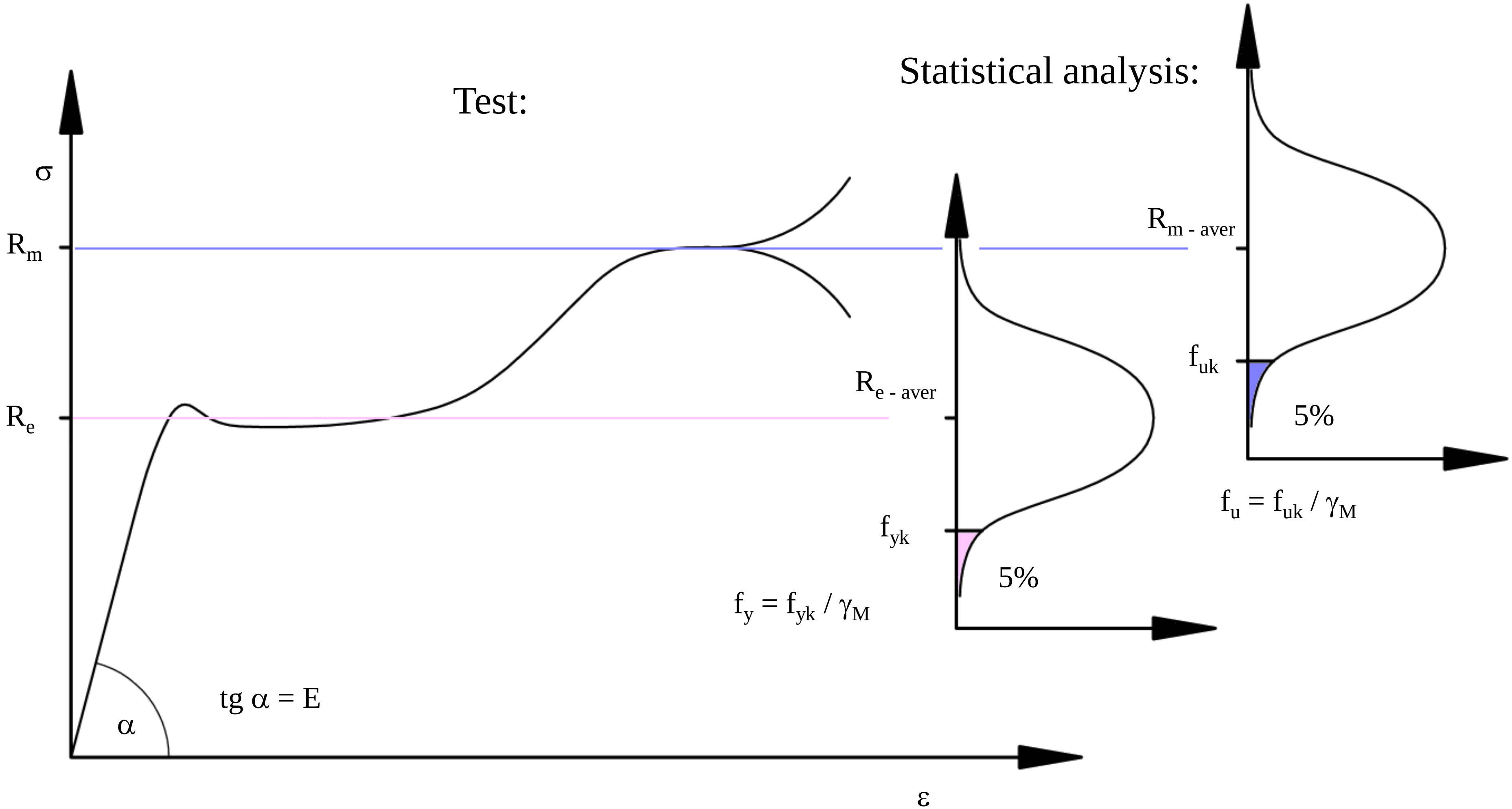

Photo: Author

Task 1a: structural steel:

Complete the table;

Based on the information in the table, determine the grade of steel (EN 1993-1-1);

Compare elongation with acceptable by the minima (EN 10025-2 ; comments);

#	Material St / Al	d_{nom} [mm]	M [kg/m]	L_e [mm]	A_5 [%]	A_{gt} [%]	R_e [MPa]	R_m [MPa]	Comments
1	X	X	X	X		X	X	X	X
2									
3									
4									
5									
6									

Task 1b: high strength steel (if will be):

Complete the table;

#	Material St / Al	d_{nom} [mm]	M [kg/m]	L_e [mm]	A_5 [%]	A_{gt} [%]	R_e [MPa]	R_m [MPa]	Comments
1	X	X	X	X		X	X	X	X
2	X	X	X	X		X		X	
3									
4									
5									
6									

No calculations, entering information only;

Task 2: aluminum (if will be):

Complete the table;

Based on the information in the table, determine the grade of aluminum (EN 1999-1-1);

#	Material St / Al	d_{nom} [mm]	M [kg/m]	L_e [mm]	A_5 [%]	A_{gt} [%]	R_e [MPa]	R_m [MPa]	Comments
1	X	X	X	X		X	X	X	X
2	X	X	X	X		X		X	
3	X	X	X	X		X		X	
4									
5									
6									

No calculations, entering information only;

Aluminum: other symbols

$$R_{02} \rightarrow f_o$$
$$R_m \rightarrow f_u$$

Information in table consists on three various group of data

#	Material St / Al	d_{nom} [mm]	M [kg/m]	L_{tot} [mm]	A_5 [%]	A_{gt} [%]	R_e [MPa]	R_m [MPa]	Comments
1	X	X	X	X		X	X	X	X
2	X	X	X	X		X		X	
3	X	X	X	X		X		X	
4									
5									
6									

Initial information about material, its density, dimension of samples;

Data from tests;

Data from calculation → #t / 31;

Data on #t / 24:

$R_e = (R_{eH} + R_{eL}) / 2 = (354 + 342) / 2 = 348$ MPa

$A_{gt} = 26{,}61$ %

$f_{y,\ aver} = R_e\ / 1{,}1$ (**assumption, because only one speciment**) = 316,364 MPa

$\sigma_y = 0{,}07\ R_e$ (**assumption, because only one speciment**) = 22,145 MPa

$f_{y,\ f} = f_{y,\ aver}$ - 1,645 σ_y = 279,934 MPa → probably steel S275 (the same type of analysis as on #t / 22)

$f_{y,\ d} = f_{y,\ k} / 1{,}0 = 279{,}934$ MPa

Comments for result: is elongation within range predicted by standards?

Minimum elongation for S275 (#t / 35 , max for all S275): 23 %

26,61 % > 22 % **OK**

EN 1993-1-1 tab 3.1: relation strength – name of steel

Standard and steel grade	Nominal thickness of the element t [mm]			
	$t \leq 40$ mm		$40 \text{ mm} < t \leq 80$ mm	
	f_y [N/mm²]	f_u [N/mm²]	f_y [N/mm²]	f_u [N/mm²]
EN 10025-2				
S 235	235	360	215	360
S 275	275	430	255	410
S 355	355	490	335	470
S 450	440	550	410	550
EN 10025-3				
S 275 N/NL	275	390	255	370
S 355 N/NL	355	490	335	470
S 420 N/NL	420	520	390	520
S 460 N/NL	460	540	430	540
EN 10025-4				
S 275 M/ML	275	370	255	360
S 355 M/ML	355	470	335	450
S 420 M/ML	420	520	390	500
S 460 M/ML	460	540	430	530
EN 10025-5				
S 235 W	235	360	215	340
S 355 W	355	490	335	490
EN 10025-6				
S 460 Q/QL/QL1	460	570	440	550

EN 1993-1-11 tab 1, tab. 2: relation strength – name of steel

EN10025-6 Steel grade and qualities	Nominal thickness of the element t mm					
	$t \leq 50$ mm		50 mm$<t\leq$100 mm		100 mm$<t\leq$150 mm	
	f_y [N/mm^2]	f_u [N/mm^2]	f_y [N/mm^2]	f_u [N/mm^2]	f_y [N/mm^2]	f_u [N/mm^2]
S 500Q/QL/QL1	500	590	480	590	440	540
S 550Q/QL/QL1	550	640	530	640	490	590
S 620Q/QL/QL1	620	700	580	700	560	650
S 690Q/QL/QL1	690	770	650	760	630	710

EN 10149-2a)	$1{,}5$ mm $\leq t \leq 8$ mm		8 mm $< t \leq 16$ mm	
	f_y [N/mm^2]	f_u [N/mm^2]	f_y [N/mm^2]	f_u [N/mm^2]
S 500MC	500	550	500	550
S 550MC	550	600	550	600
S 600MC	600	650	600	650
S 650MC	650	700	630	700
S 700MC	700	750	680	750

a) Verification of the impact energy in accordance with EN 10149-1 Clause 11, Option 5 should be specified.

EN 10025-2 Hot rolled products for structural steel; technical delivery conditions for non-alloy structural steel: relation strength – name of steel (more accurate)

Table 7 - Mechanical properties at ambient temperature for flat and long products of steel grades and qualities with values for the impact strength

Designation		Minimum yield strength R_{eH} [a] MPa[b] Nominal thickness mm									Tensile strength R_m [a] MPa[b] Nominal thickness mm				
According EN 10027-1 and CR 10260	According EN 10027-2	≤ 16	> 16 ≤ 40	> 40 ≤ 63	> 63 ≤ 80	> 80 ≤ 100	> 100 ≤ 150	> 150 ≤ 200	> 200 ≤ 250	> 250 ≤ 400[c]	< 3	≥ 3 ≤ 100	> 100 ≤ 150	> 150 ≤ 250	> 250 ≤ 400[c]
S235JR	1.0038	235	225	215	215	215	195	185	175	-	360 to 510	360 to 510	350 to 500	340 to 490	-
S235J0	1.0114	235	225	215	215	215	195	185	175	-	360 to 510	360 to 510	350 to 500	340 to 490	-
S235J2	1.0117	235	225	215	215	215	195	185	175	165	360 to 510	360 to 510	350 to 500	340 to 490	330 to 480
S275JR	1.0044	275	265	255	245	235	225	215	205	-	430 to 580	410 to 560	400 to 540	380 to 540	-
S275J0	1.0143	275	265	255	245	235	225	215	205	-	430 to 580	410 to 560	400 to 540	380 to 540	-
S275J2	1.0145	275	265	255	245	235	225	215	205	195	430 to 580	410 to 560	400 to 540	380 to 540	380 to 540
S355JR	1.0045	355	345	335	325	315	295	285	275	-	510 to 680	470 to 630	450 to 600	450 to 600	-
S355J0	1.0553	355	345	335	325	315	295	285	275	-	510 to 680	470 to 630	450 to 600	450 to 600	-
S355J2	1.0577	355	345	335	325	315	295	285	275	265	510 to 680	470 to 630	450 to 600	450 to 600	450 to 600
S355K2	1.0596	355	345	335	325	315	295	285	275	265	510 to 680	470 to 630	450 to 600	450 to 600	450 to 600
S450J0[d]	1.0590	450	430	410	390	380	380	-	-	-	-	550 to 720	530 to 700	-	-

[a] For plate, strip and wide flats with widths ≥ 600 mm the direction transverse (t) to the rolling direction applies. For all other products the values apply for the direction parallel (l) to the rolling direction.

[b] 1 MPa = 1 N/mm^2.

[c] The values apply to flat products.

[d] Applicable for long products only.

(To be continued)

EN 10025-2 Accepted elongation for various grades of steel

Table 7 - Mechanical properties at ambient temperature for flat and long products of steel grades and qualities with values for the impact strength (*concluded*)

Designation		Position of test pieces [a]	Minimum percentage elongation after fracture [a] %										
			L_0 = 80 mm Nominal thickness mm					$L_0 = 5,65 \sqrt{S_0}$ Nominal thickness mm					
According EN 10027-1 and CR 10260	According EN 10027-2		≤ 1	> 1 ≤ 1,5	> 1,5 ≤ 2	> 2 ≤ 2,5	> 2,5 < 3	≥ 3 ≤ 40	> 40 ≤ 63	> 63 ≤ 100	> 100 ≤ 150	> 150 ≤ 250	> 250[c] ≤ 400 only for J2 and K2
S235JR S235J0 S235J2	1.0038 1.0114 1.0117	l t	17 15	18 16	19 17	20 18	21 19	26 24	25 23	24 22	22 22	21 21	- - 21 (l and t)
S275JR S275J0 S275J2	1.0044 1.0143 1.0145	l t	15 13	16 14	17 15	18 16	19 17	23 21	22 20	21 19	19 19	18 18	- - 18 (l and t)
S355JR S355J0 S355J2 S355K2	1.0045 1.0553 1.0577 1.0596	l t	14 12	15 13	16 14	17 15	18 16	22 20	21 19	20 18	18 18	17 17	- - 17 (l and t) 17 (l and t)
S450J0[d]	1.0590	l	-	-	-	-	-	17	17	17	17	-	-

[a] For plate, strip and wide flats with widths ≥ 600 mm the direction transverse (t) to the rolling direction applies. For all other products the values apply for the direction parallel (l) to the rolling direction.

[c] The values apply to flat products.

[d] Applicable for long products only.

EN 10025-2 Accepted elongation for various grades of steel

Table 8 - Mechanical properties at ambient temperature for flat and long products of steel grades with no values for the impact strength

Designation		Minimum yield strength R_{eH} [a] MPa[b] Nominal thickness mm								Tensile strength R_m [a] MPa[b] Nominal thickness mm			
According EN 10027-1 and CR 10260	According EN 10027-2	≤ 16	> 16 ≤ 40	> 40 ≤ 63	> 63 ≤ 80	> 80 ≤ 100	> 100 ≤ 150	> 150 ≤ 200	> 200 ≤ 250	< 3	≥ 3 ≤ 100	> 100 ≤ 150	> 150 ≤ 250
S185	1.0035	185	175	175	175	175	165	155	145	310 to 540	290 to 510	280 to 500	270 to 490
E295[c]	1.0050[c]	295	285	275	265	255	245	235	225	490 to 660	470 to 610	450 to 610	440 to 610
E335[c]	1.0060[c]	335	325	315	305	295	275	265	255	590 to 770	570 to 710	550 to 710	540 to 710
E360[c]	1.0070[c]	360	355	345	335	325	305	295	285	690 to 900	670 to 830	650 to 830	640 to 830

[a] For plate, strip and wide flats with widths ≥ 600 mm the direction transverse (t) to the rolling direction applies. For all other products the values apply for the direction parallel (l) to the rolling direction.

[b] 1 MPa = 1 N/mm^2.

[c] These steels are normally not used for channels, angles and sections.

(*To be continued*)

EN 10025-2 Accepted elongation for various grades of steel

Table 8 - Mechanical properties at ambient temperature for flat and long products of steel grades with no values for the impact strength (*concluded*)

Designation		Position of test pieces [a]	Minimum percentage elongation after fracture [a] %									
			L_0 = 80 mm Nominal thickness mm					$L_0 = 5,65\sqrt{S_0}$ Nominal thickness mm				
According EN 10027-1 and CR 10260	According EN 10027-2		≤ 1	> 1 ≤ 1,5	> 1,5 ≤ 2	> 2 ≤ 2,5	> 2,5 < 3	≥ 3 ≤ 40	> 40 ≤ 63	> 63 ≤ 100	> 100 ≤ 150	> 150 ≤ 250
S185	1.0035	l	10	11	12	13	14	18	17	16	15	15
		t	8	9	10	11	12	16	15	14	13	13
E295[c]	1.0050[c]	l	12	13	14	15	16	20	19	18	16	15
		t	10	11	12	13	14	18	17	16	15	14
E335[c]	1.0060[c]	l	8	9	10	11	12	16	15	14	12	11
		t	6	7	8	9	10	14	13	12	11	10
E360[c]	1.0070[c]	l	4	5	6	7	8	11	10	9	8	7
		t	3	4	5	6	7	10	9	8	7	6

[a] For plate, strip and wide flats with widths ≥ 600 mm the direction transverse (t) to the rolling direction applies. For all other products the values apply for the direction parallel (l) to the rolling direction.

[c] These steels are normally not used for channels, angles and sections.

EN 1999-1-1 tab 3.2: relation strength – name of aluminum

Alloy EN-AW	Temper [1)]	Thick-ness mm [1)]	f_o [1)]	f_u	A_{50} [1) 6)]	$f_{o,haz}$ [2)]	$f_{u,haz}$ [2)]	HAZ-factor [2)] $\rho_{o,haz}$ [1)]	$\rho_{u,haz}$	BC 4)	n_p 1), 5)
			N/mm²		%	N/mm²					
3004	H14 ∣ H24/H34	≤ 6 ∣ 3	180 ∣ 170	220	1 ∣ 3	75	155	0,42 ∣ 0,44	0,70	B	23 ∣ 18
	H16 ∣ H26/H36	≤ 4 ∣ 3	200 ∣ 190	240	1 ∣ 3			0,38 ∣ 0,39	0,65	B	25 ∣ 20
3005	H14 ∣ H24	≤ 6 ∣ 3	150 ∣ 130	170	1 ∣ 4	56	115	0,37 ∣ 0,43	0,68	B	38 ∣ 18
	H16 ∣ H26	≤ 4 ∣ 3	175 ∣ 160	195	1 ∣ 3			0,32 ∣ 0,35	0,59	B	43 ∣ 24
3103	H14 ∣ H24	≤ 25 ∣ 12,5	120 ∣ 110	140	2 ∣ 4	44	90	0,37 ∣ 0,40	0,64	B	31 ∣ 20
	H16 ∣ H26	≤ 4	145 ∣ 135	160	1 ∣ 2			0,30 ∣ 0,33	0,56	B	48 ∣ 28
5005/ 5005A	O/H111	≤ 50	35	100	15	35	100	1	1	B	5
	H12 ∣ H22/H32	≤ 12,5	95 ∣ 80	125	2 ∣ 4	44	100	0,46 ∣ 0,55	0,80	B	18 ∣ 11
	H14 ∣ H24/H34	≤ 12,5	120 ∣ 110	145	2 ∣ 3			0,37 ∣ 0,40	0,69	B	25 ∣ 17
5052	H12 ∣ H22/H32	≤ 40	160 ∣ 130	210	4 ∣ 5	80	170	0,50 ∣ 0,62	0,81	B	17 ∣ 10
	H14 ∣ H24/H34	≤ 25	180 ∣ 150	230	3 ∣ 4			0,44 ∣ 0,53	0,74	B	19 ∣ 11
5049	O / H111	≤ 100	80	190	12	80	190	1	1	B	6
	H14 ∣ H24/H34	≤ 25	190 ∣ 160	240	3 ∣ 6	100	190	0,53 ∣ 0,63	0,79	B	20 ∣ 12
5454	O/H111	≤ 80	85	215	12	85	215	1	1	B	5
	H14∣H24/H34	≤ 25	220 ∣ 200	270	2 ∣ 4	105	215	0,48 ∣ 0,53	0,80	B	22 ∣ 15
5754	O/H111	≤ 100	80	190	12	80	190	1	1	B	6
	H14∣H24/H34	≤ 25	190 ∣ 160	240	3 ∣ 6	100	190	0,53 ∣ 0,63	0,79	B	20 ∣ 12
5083	O/H111	≤ 50	125	275	11	125	275	1	1	B	6
		50<t≤80	115	270	14 [5)]	115	270			B	
	H12∣H22/H32	≤ 40	250 ∣ 215	305	3 ∣ 5	155	275	0,62 ∣ 0,72	0,90	B	22 ∣ 14
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]

<u>Hardness</u>

measure of how resistant solid matter is to various kinds of permanent shape change when a force is applied

- Brinell
- Vickers
- Rockwell

- Poldi

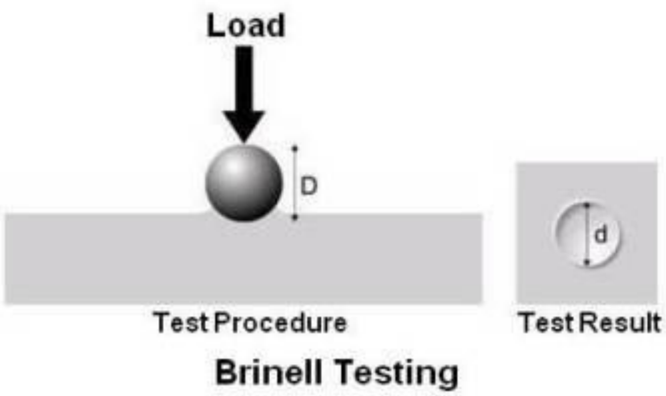

Photo: practicalmaintenance.net

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Brinell (EN ISO 6506)

$$HB = 0,204\ F / \{\pi D\ [\ D - \sqrt{(D^2 - d^2)}]\}$$
$$d = (d_1 + d_2) / 2$$

$$R_m \approx 3,33\ HB\ (125 < HB < 175)$$
$$R_m \approx 3,53\ HB\ (HB > 175)$$

We can identify the grade of steel in non-destructive test

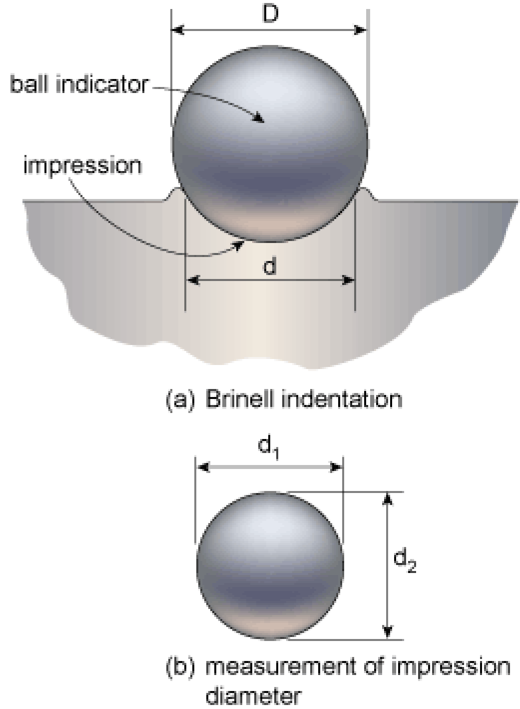

Photo: twi-global.com

→ #2 / 60

Poldi

spherical probe, calculations the same as for Brinell

Photo: metale24.pl

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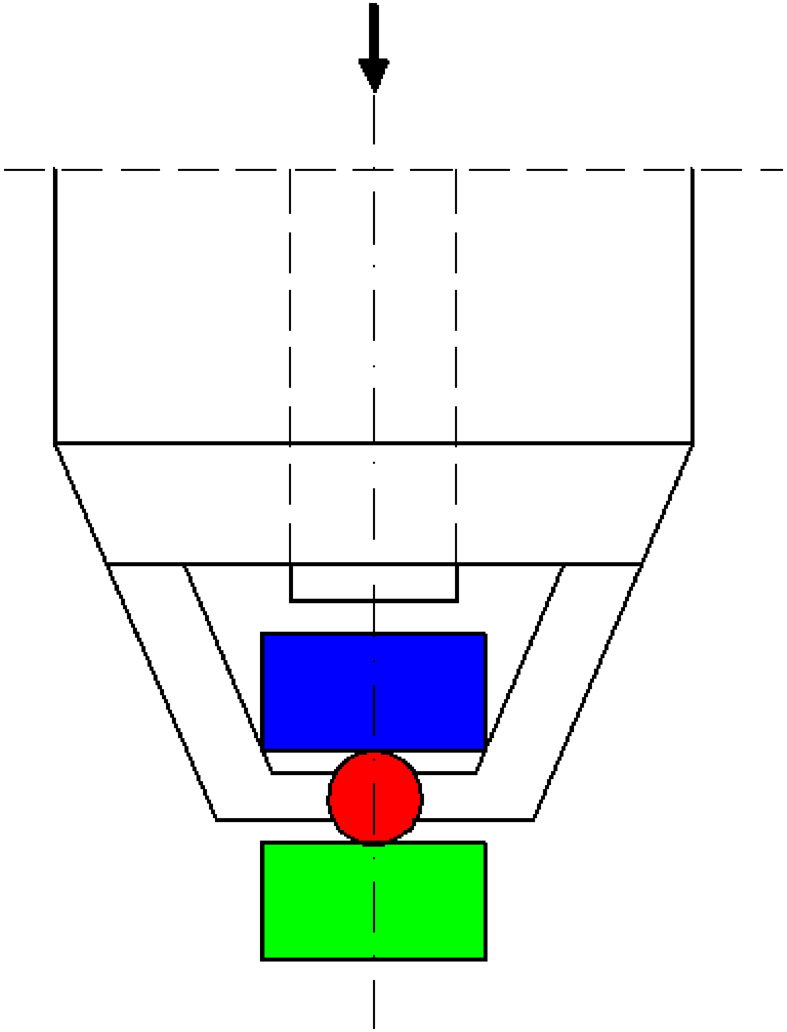


Photo: Author

Pattern

Probe

Test material

Main idea: test holes are formed in the pattern and the test material under the influence of the same force

→ #2 / 65

$$HB = HB_p [D - \sqrt{(D^2 - d_p^2)}] / [D - \sqrt{(D^2 - d^2)}]$$

HB_p - HB of the pattern (known)

D - diameter of the probe (known)

d - diameter hole in the test material (measured)

d_p - diameter hole in the test pattern (measured)

HB → R_m → grade of steel

We no need to know value of force

Very old steel strucures, no documentation on steel grade:

Photo: wikipedia

Photo: oceanmachinery.com

Cutting part of structure and testing in UTS; very accurate results, but destruction of part of the structure.

→ #2 / 66

Photo: ndtteknik.com

In situ testing with a Poldi hammer; approximate results, but undamaged construction.

Standarized test:

D = 5 mm

F = 29 400 N (3 000 kG)

T = 10-15 s

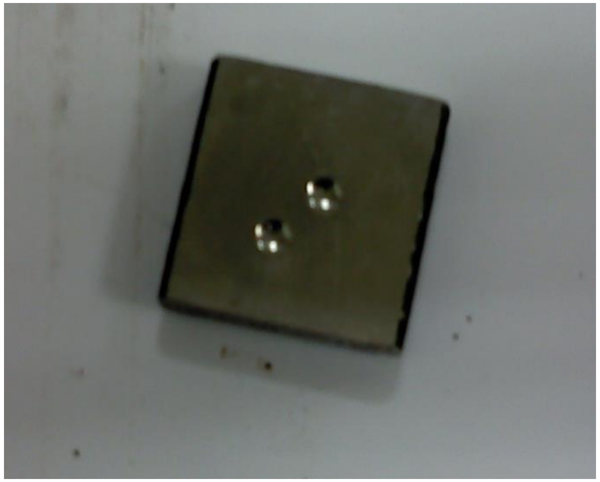
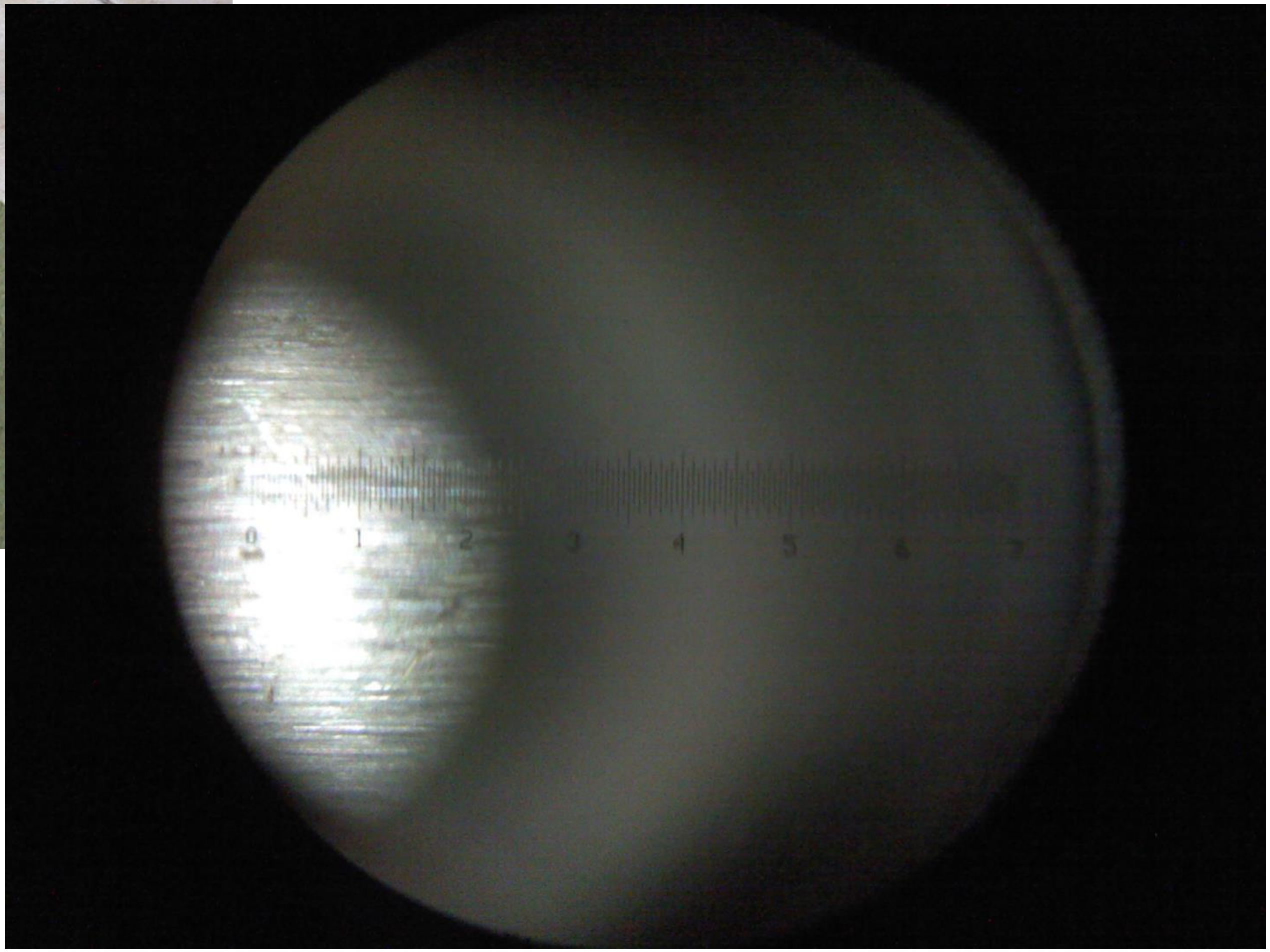


Photo:Author

Then we measure diameter of print, using scale in microscope.

Photo:Author



Task 3: Hardness

Complete the table;

Based on the information in the table, determine the grade of steel;

#	F [kN]	t [s]	d_1 [mm]	d_2 [mm]	$d_{average}$ [mm]	HB [MPa]	R_m [MPa]	Steel
1								
2								
3								
4								

$F = 29\ 400$ N

$t = 12$ s

$d_1 = 4{,}2$ mm

$d_2 = 4{,}1$ mm

$d_{average} = 4{,}05$ mm

$HB = 0{,}204\ F / \{\pi D\ [\ D - \sqrt{(D^2 - d^2)}]\} = 178{,}759$ MPa

$R_m \approx 3{,}53\ HB = 631{,}020$ MPa $\rightarrow f_u \approx 630$ MPa $\rightarrow$

$\rightarrow$ #t / 33 for thickness ≤ 40 mm $\rightarrow$

$\rightarrow$ probably S 550 Q

Impact resistance

the ability of a material to absorb energy and plastically deform without fracturing

Shapre of specimen → #2 / 67

(notch U or V)

EN 10 045-1

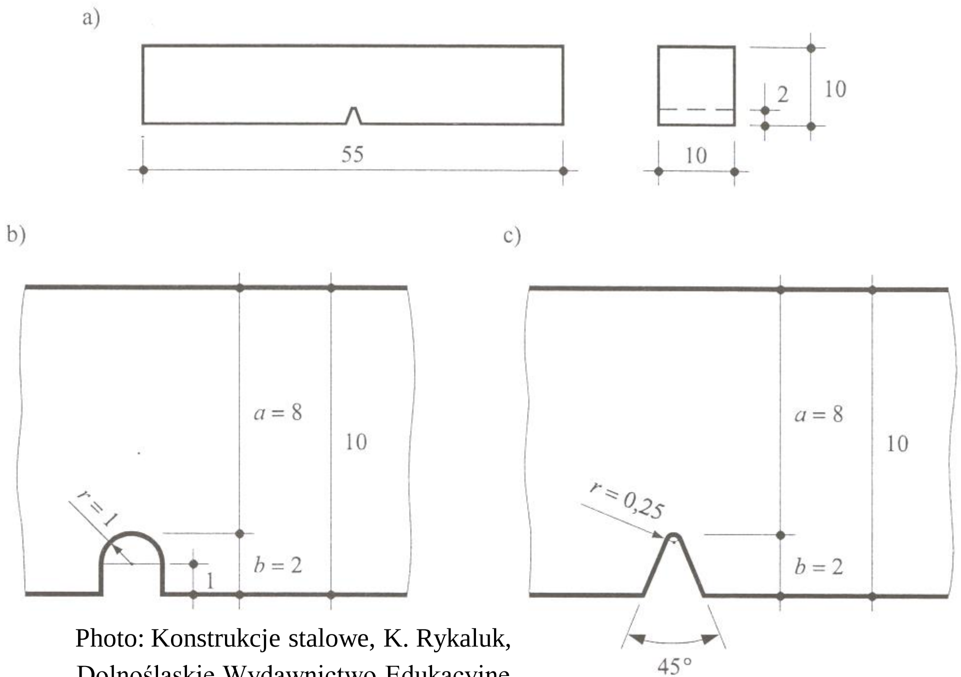


Photo: Konstrukcje stalowe, K. Rykaluk, Dolnośląskie Wydawnictwo Edukacyjne Wrocław 2001

Photo: ccsi-inc.com

Energy of hammer at the start position: G h

Energy of hammer at the end position: $G h_1$

Energy absorbed by a material during fracture for notch U or V:

$KCU\ (KCV) = G (h - h_1)$ [J]

There are two alternative measures of impact resistance:

- energy [J];
- energy / area of speciment [J / cm^2];

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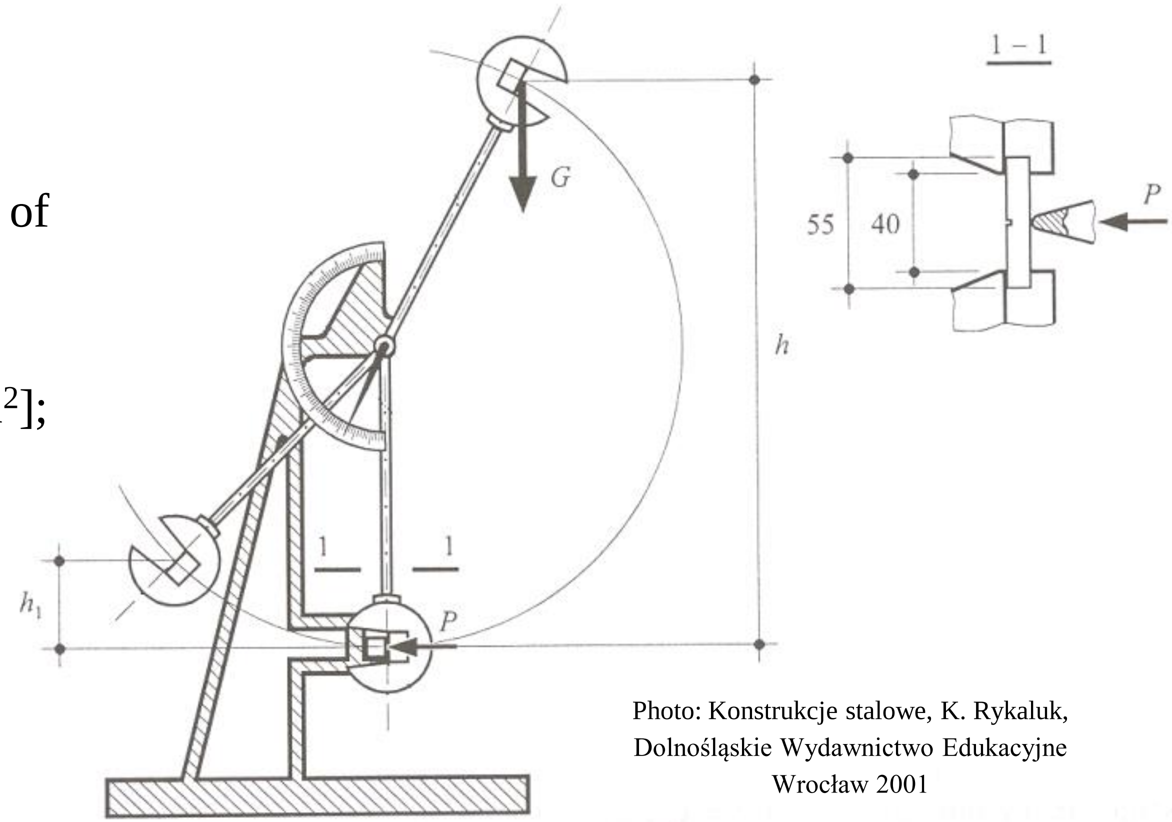

Photo: Konstrukcje stalowe, K. Rykaluk, Dolnośląskie Wydawnictwo Edukacyjne Wrocław 2001

Results of tests:

1. fracture without separation (left)
2. fracture with separation (right)

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KC(1) > KC(2)

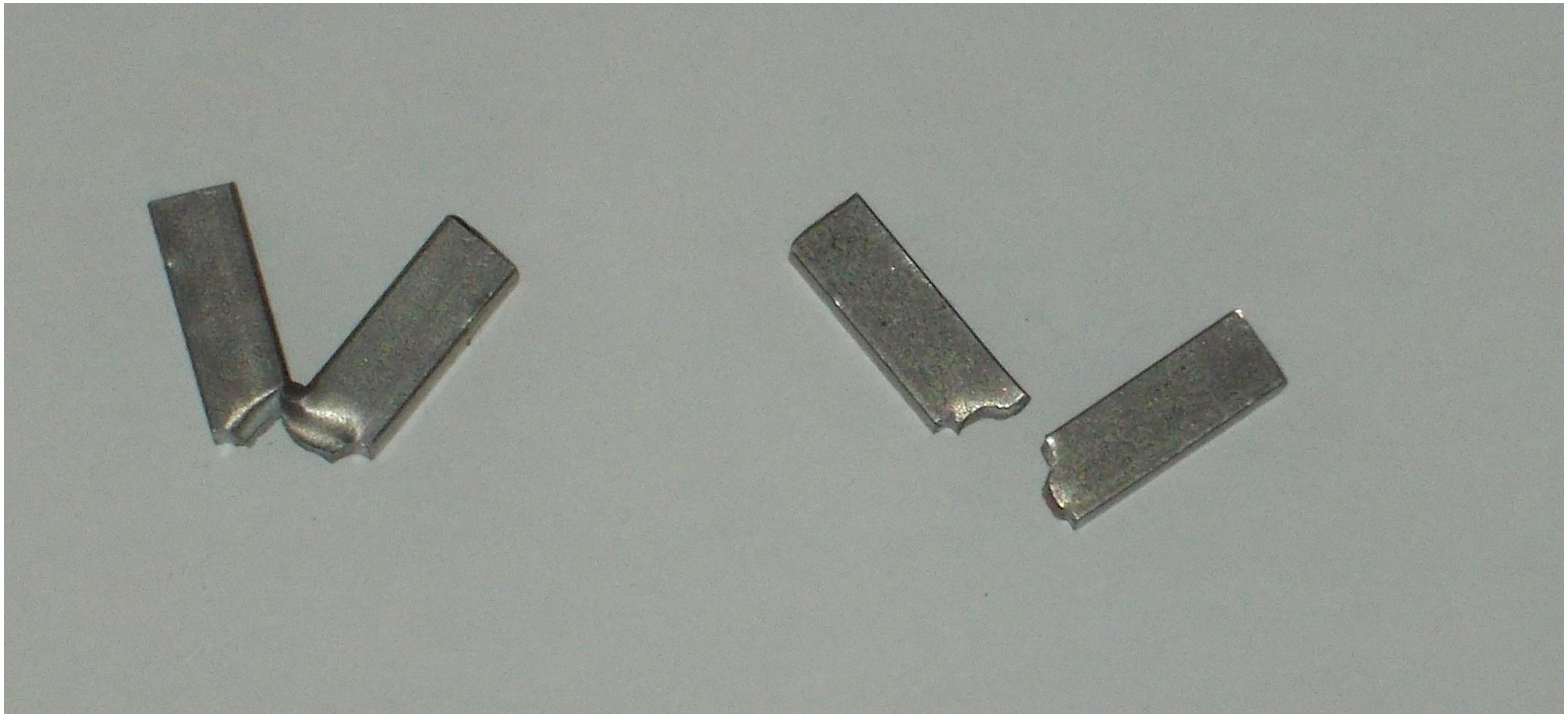

Photo: Author

Undesired situation: it is impossible to determine fracture energy of sample and subrgade of steel. Test must be repeated for higher hammer energy.

Desired situation: it is possible to determine fracture energy of sample and subrgade of steel

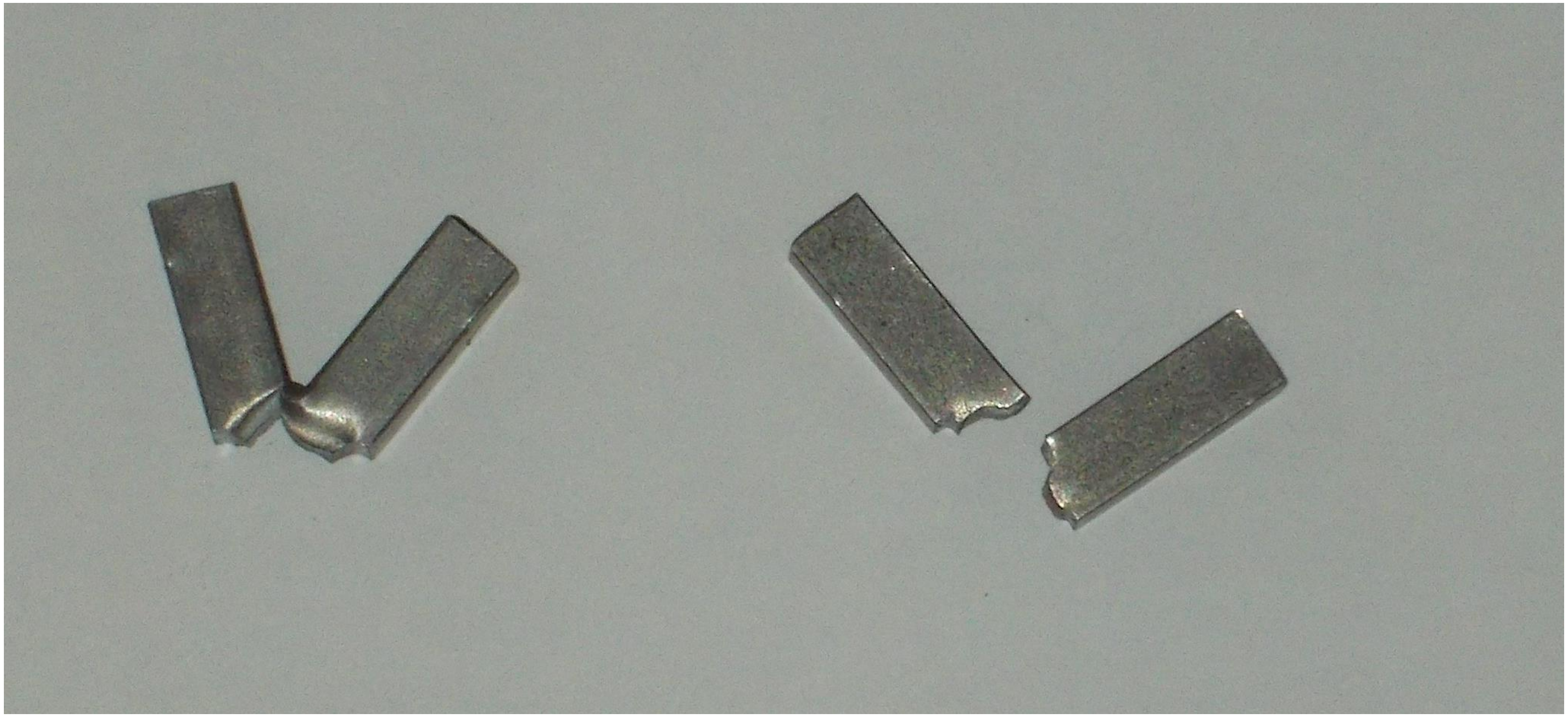

Photo: Author

Why impact resistance is important?

Photo: inspectioneering.com

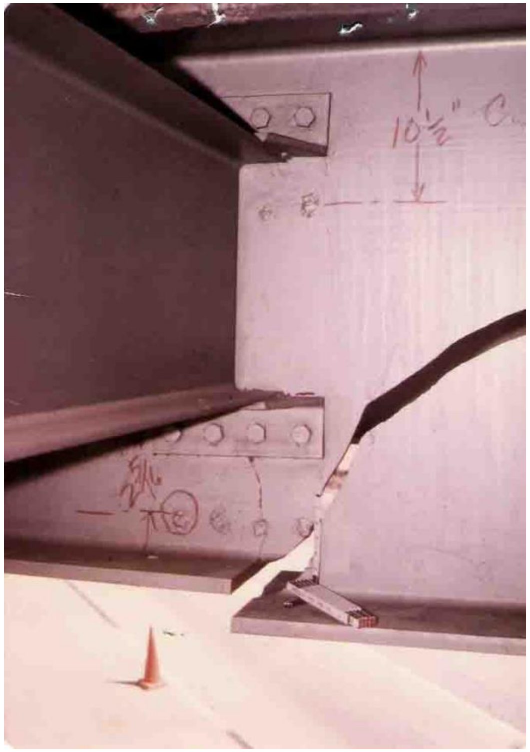

Photo: rebar.ecn.purdue.edu

Photo: civildigital.com

Result of Charpy hammer test shows susceptibility to brittle cracking of various grades of steel.

→ #2 / 71

Photo: wikipedia

Photo: globalnpsolutions.com

Susceptibility to brittle cracking increases when:

- ↓ temperature;
- ↑ stresses;
- ↑ thickness of elements;

→ #2 / 72

EN 1993-1-10 tab 2.1

Reference temperature T_{Ed} [°C], $\sigma_{Ed} = 0{,}75\, f_y(t)$

Steel grade	Sub-grade	KV at T [°C]	KV J_{min}	10	0	-10	-20	-30	-40	-50
S235	JR	20	27	60	50	40	35	30	25	20
	J0	0	27	90	75	60	50	40	35	30
	J2	-20	27	125	105	90	75	60	50	40
S275	JR	20	27	55	45	35	30	25	20	15
	J0	0	27	75	65	55	45	35	30	25
	J2	-20	27	110	95	75	65	55	45	35
	M,N	-20	40	135	110	95	75	65	55	45
	ML,NL	-50	27	185	160	135	110	95	75	65
S355	JR	20	27	40	35	25	20	15	15	10
	J0	0	27	60	50	40	35	25	20	15

Reference temperature T_{Ed} [°C], $\sigma_{Ed} = 0{,}50\, f_y(t)$

Steel grade	Sub-grade	10	0	-10	-20	-30	-40	-50
S235	JR	90	75	65	55	45	40	35
	J0	125	105	90	75	65	55	45
	J2	170	145	125	105	90	75	65
S275	JR	80	70	55	50	40	35	30
	J0	115	95	80	70	55	50	40
	J2	155	130	115	95	80	70	55
	M,N	180	155	130	115	95	80	70
	ML,NL	200	200	180	155	130	115	95
S355	JR	65	55	45	40	30	25	25
	J0	95	80	65	55	45	40	30

Reference temperature T_{Ed} [°C], $\sigma_{Ed} = 0,$

Steel grade	Sub-grade	10	0	-10	-2
S235	JR	135	115	100	8
	J0	175	155	135	11
	J2	200	200	175	15
S275	JR	125	110	95	8
	J0	165	145	125	11
	J2	200	190	165	14
	M,N	200	200	190	16
	ML,NL	230	200	200	20
S355	JR	110	95	80	7
	J0	150	130	110	9

Low temperature + big values of stresses → too thick elements are prohibited

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Symbols of different subrages of steel

→ #2 / 70

EN 10025-2 tab. 9

T [^oC]	KV [J]		
	27	40	60
+20	JR	KR	LR
0	J0	K0	L0
-20	J2	K2	L2
-30	J3	K3	L3
-40	J4	K4	L4
-50	J5	K5	L5
-60	J6	K6	L6

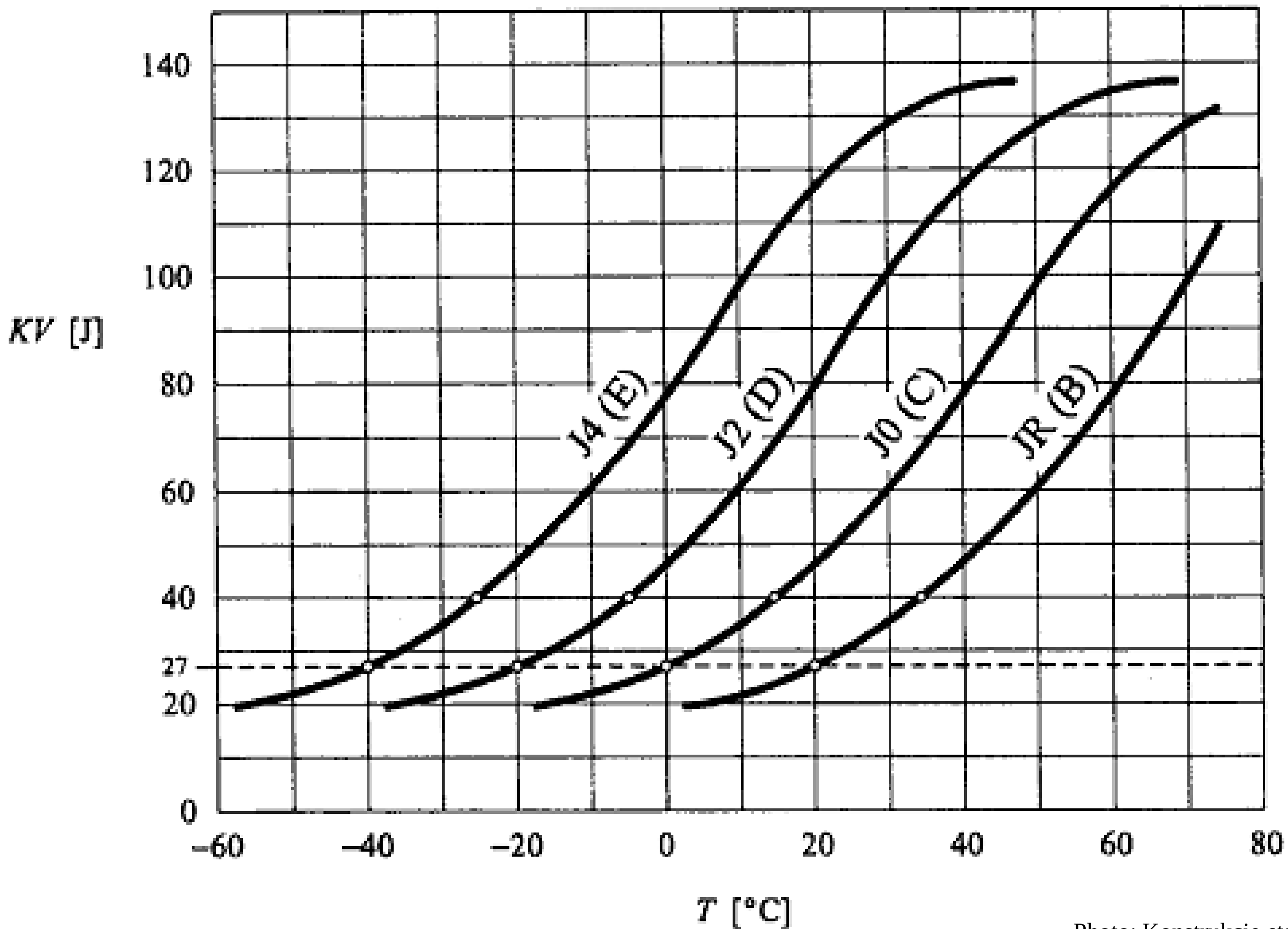


Photo: Konstrukcje stalowe, K. Rykaluk,
Dolnośląskie Wydawnictwo Edukacyjne
Wrocław 2001

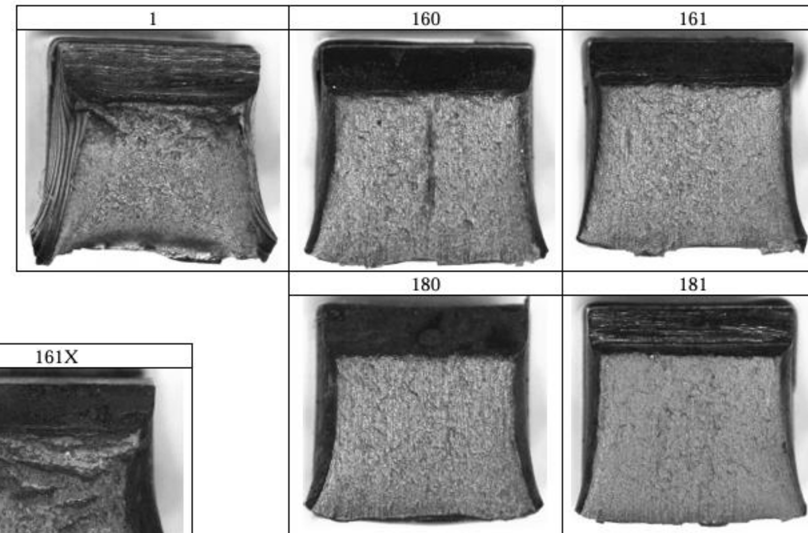
Brittle fracture - low resistance of steel to cracking at low temperatures

Ductile fracture - high resistance of steel to cracking at low temperatures

Photo: *Identyfikacja kryteriów pękania plastycznego w oparciu o wyniki badań doświadczalnych*, L. Trębacz

In addition to testing for crack susceptibility, Charpy test can also be used to assess degree of steel degradation in structures damaged by fire. This involves answering the question: „can the structure continue to be safely used or is it only suitable for demolition?”

Photo: easternontarionetwork.com



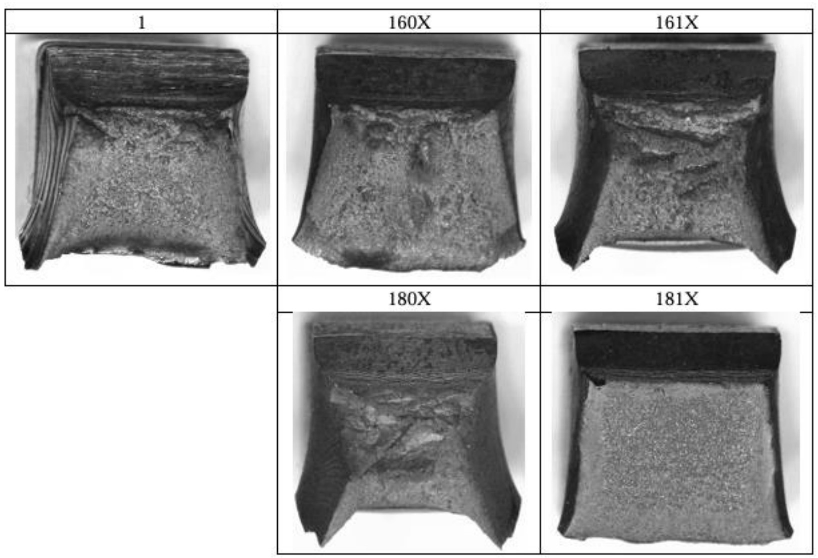


Photo: *Po-pożarowa degradacja wybranych stali stosowanych w budownictwie w świetle wyników eksperymentalnych uzyskanych w zinstrumentalizowanej próbie udarności Charpy'ego*, P. Zajdel

Task 4: Charpy hammer:

Complete the table;

Based on the information in the table, determine the subgrade of steel;

#	T [°C]	Notch (U/V)	KU / KV [J]	Grade
1				
2				
3				
4				

6,30 kg m = 61,8 J

T ≈ 20°C

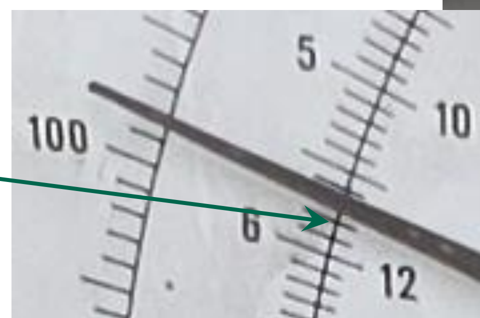


Photo:Author

20°C and 61,8 J → according to t# / 55 subgrade LR

Universal testing machine - maszyan wytrzymałościowa
Yeld strength - granica plastyczności
Ultimate tensile strength - granica wytrzymałości (na rozciąganie)
Hardness - twardość
Impact resistance – udarność
Normal distribution - rozkład normalny
Cumulative distribution function - dystrybuanta (funkcja Laplace’a)
Quantile function - odwrotna dystrybuanta (odwrotna funkcja Laplace’a)
Average value - wartość średnia
Standard derivation - odchylenie standardowe

Thank you for attention

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