

FLANGING, RAEX[®] WEAR- RESISTANT STEELS, ULTRA HIGH-STRENGTH OPTIM[®] QC STEELS

HOT-ROLLED STEEL PLATES AND COILS

RUUKKI

Energy-efficient steel solutions for better LIVING. WORKING. MOVING.

- **Introduction**

Raex is a wear-resistant steel grade with excellent hardness and strength properties. Raex steels are delivered as hardened cut lengths and hardened heavy plates. Optim QC is a high-strength structural steel that is also suitable for application requiring moderate abrasion resistance. Optim QC is delivered as hardened cut lengths. The flanging of hardened steels is challenging due to the very high strength of steels. The need for bending force, the level of spring-back and the minimum permitted bending radius increase as the strength of steel increases. Flanging tools must be in good conditions and as high a bending radius as possible must be used. This brochure describes the principles of free bending and bottoming and gives practical recommended values for the flanging of hardened steels.

In order to compare the cold forming properties of various steel grades, the minimum bending radii are tabulated on the brochure. The bending radii tabulated include Ruukki's structural steels, structural standard steels and Raex wear-resistant steels.

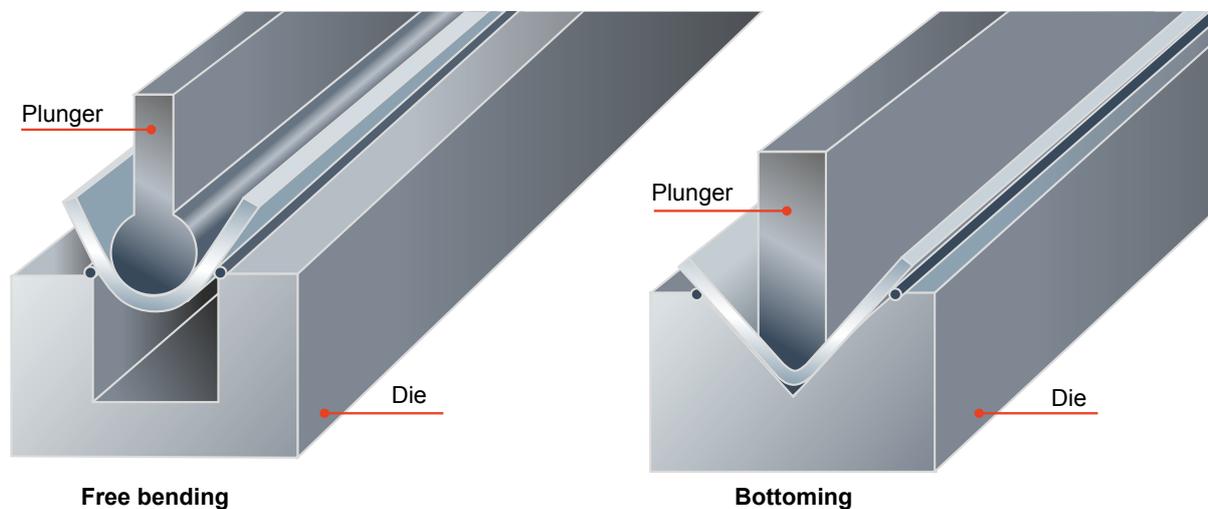
- **Flanging methods**

The plate is bent to the designed angle or free bending radius in a flanging press between the plunger and the die.

In free bending, the plate rests on the upper edges of the die gap for the entire duration of the pass. The required bending radius is obtained by adjusting the stroke length (Figure 1). The die gap width can be adjusted.

In bottoming, the stroke length is sufficient for the plunger to press the plate entirely against the die. An edge matching that of the plunger and die is formed in the plate (Figure 1). The die gap (V-groove) is fixed and its width cannot be adjusted.

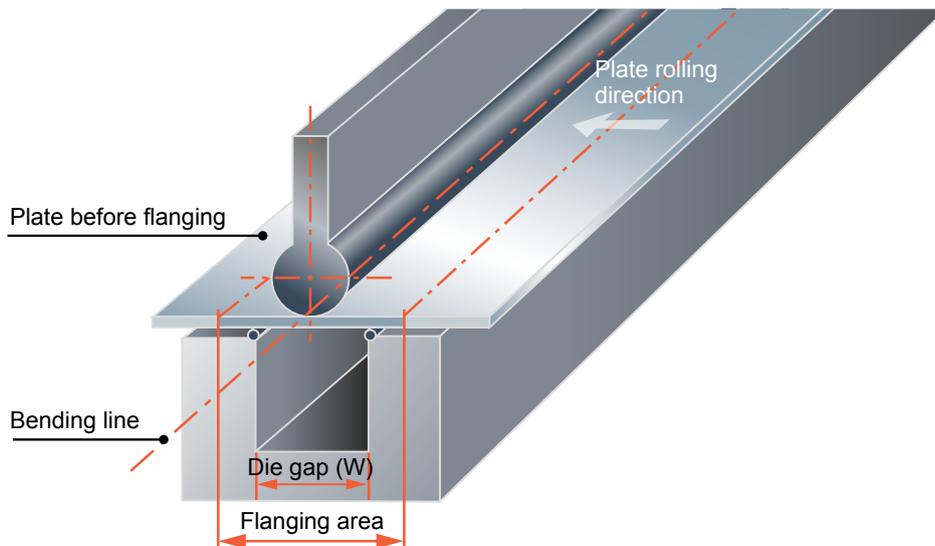
Figure 1. Flanging methods and tools



- **Flanging preparations**

- The temperature of the plate to be flanged must be a minimum of +20 °C
- It is recommended to bring plates stored in cold places indoors a day prior to flanging
- If required, the area to be flanged must be heated using a gas flame
- Preheating to +100 – +200°C reduces the required bending force and improves flangeability in general
- Identify the rolling direction of the plate
- Possible surface defects must be grind away from the tension side face of the plate
- Grind away defects on the cut edge of a thermally or mechanically cut plate, at least on the area to be flanged.

Figure 2. Flanging preparations. Bending transverse to the rolling direction



- **Instructions for flanging**

- Safety instructions must be followed in flanging
- The need for bending force, springback effect and the permitted bending radius increase as the strength of the steel increases
- The widest possible bending radius must be used
- Flanging must be made in a single pass
- The best possible workshop expertise can be obtained by combining theoretical data and experience
- Bending values are defined on the basis of test bending taking the degree of the springback effect into consideration
- Springback effect in Raex 400 is 9° – 13° and Raex 500 10° – 15°
- The springback effect of Optim QC steels has to be defined in test bending.

The plunger diameter is defined on the basis of steel grade, plate thickness and bending radius. Table 1 (Raex) and Table 3 (Optim QC) present the plate thickness (t) obtained from the workpiece design, internal bending radius (R) of the flange and plunger diameter (D) for respective steel grades.

- **Bending force**

The bending force (F, in Newton) needed when flanging of steel plates can be estimated using the following formula:

$$F = C \cdot \frac{R_m \cdot b \cdot t^2}{W}$$

R_m = tensile strength, N/mm² (=MPa)

t = plate thickness, mm

C = constant ≈ 1.6 – 1.8 (hardened steels)

C = constant ≈ 1.2 – 1.5 (structural steels)

b = bending length, mm

W = die gap, mm

The typical tensile strength of Raex wear-resistant steels and ultra high-strength Optim QC structural steels is presented in Tables 2 and 4.

Table 1. Raex wear-resistant steels. Flanging instructions for customer's workshop. Selection of the minimum allowed plunger diameter on the basis of steel grade, plate thickness and bending radius

Plunger diameter D mm	Bending radius R mm	Raex 400		Raex 450		Raex 500	
		Plate thickness t mm to be transversely ¹⁾ flanged	Plate thickness t mm to be longitudinally ¹⁾ flanged	Plate thickness t mm to be transversely ¹⁾ flanged	Plate thickness t mm to be longitudinally ¹⁾ flanged	Plate thickness t mm to be transversely ¹⁾ flanged	Plate thickness t mm to be longitudinally ¹⁾ flanged
12	6	2					
16	8		2				
18	9	3					
24	12	4	3	3			
30	15	5			3	3	
36	18	6	4	4			3
40	20		5	5	4	4	
50	25	8	6	6			4
56	28	9	7	7	5	5	
60	30	10					5
72	36	12	8	8	7	7	6
80	40	13	10	10			
100	50	16	12	12		10	8
110	55	18			10		
120	60	20	15	15			10
140	70				14	14	
170	85		20	20			14
200	100				20	20	
240	120						20

¹⁾ Bending line vs. plate rolling direction.

When bending in V groove (90°) the recommended gap width and plate thickness ratio is $W/t \approx 15$.

Table 2. Raex wear-resistant steels. Typical tensile strength and hardness values

Steel grade	Tensile strength R_m MPa	Hardness HBW
Raex 300	1000	300
Raex 400	1250	400
Raex 450	1450	450
Raex 500	1600	500

Table 3. Ultra high-strength Optim QC structural steels. Flanging instructions for customer's workshop
Selection of the minimum allowed plunger diameter on the basis of steel grade, plate thickness and bending radius

Plunger diameter D mm ¹⁾	Bending radius R mm	Optim 900 QC Plate thickness t mm to be flanged ¹⁾	Optim 960 QC ²⁾ Plate thickness t mm to be flanged ¹⁾	Optim 1100 QC Plate thickness t mm Bend line position vs. rolling direction in any direction Bending radius
18	9	3	2.5	
20	10			2.5
24	12	4	3	3
28	14		4	
30	15	5		
32	16			4
34	17			
38	19	6	5	
40	20			5
44	22		6	
48	24	8		
50	25			6
56	28		8	7

¹⁾ Any bending line vs. plate rolling direction can be used.

When bending in V groove (90°) the recommended gap width and plate thickness ratio is $W/t \approx 15$.

²⁾ The minimum bending radii apply also for the weathering ultra high-strength Optim 960 W steel grade.

Table 4. Ultra high-strength Optim QC structural steels. Minimum tensile strength

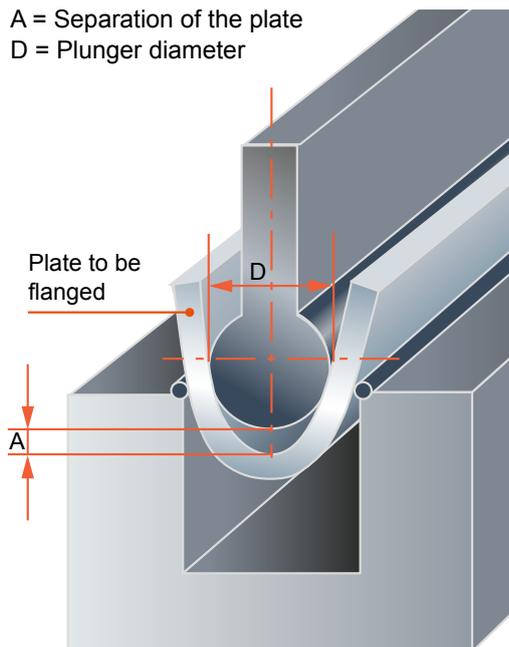
Steel grade	Tensile strength R_m MPa
Optim 900 QC	950
Optim 960 QC	1000
Optim 1100 QC	1250



- **Separation of the plate to be flanged**

Figure 3 shows the separation (A) of the plate to be flanged from the circle of the plunged diameter (D). The separation is well-known for the engineering works that are using high strength steels (yield strength 500 MPa minimum). Generally, while flanging, the accuracy of the final bend angle is more important than the radius of the bended work piece. If the exact bend radius is desired, too, trial bending has to be carried out. As a result of the trial bending, a plunger radius is selected that produces a final bend angle matching the target value. In practice, the plunger radius is a little bit larger than the directive bending radius of the steel given on the data sheet.

Figure 3. Separation of the plate to be flanged



- **Minimum bending radius**

Bending and/or flanging means that the steel is cold formed, that is, it is formed at room temperature or at a slightly elevated temperature. Cold forming properties have played an essential role in the development of steel products. Table 5 and 6 show the minimum bending radii for structural steels per steel grade and thickness range (Table 5: the Ruukki structural steels and Table 6: the standard structural steels manufactured by Ruukki). Table 7 shows the minimum bending radii for Raex wear-resistant steels.

The tight bending radii of the Optim 700 MC Plus grade serve as a good example of great developments in the cold forming properties of steel, Table 5. For example, the bending radius for this 8 mm thick thermomechanically rolled steel sheet is only $1.0 \times \text{thickness} = 8 \text{ mm}$. It is also worth noting that this is a steel grade of the yield strength class of 700 MPa!

NOTE: Tables 5, 6 and 7 list the minimum inside bending radii. In flanging in the engineering works, it is recommendable to use inside bending radii which are greater than the minimum allowed bending radii. In addition to the steel plate, the quality of the bend depends on the bending tools and the performance of the work. Successful bending requires good engineering workshop technology from the steel product processor. Worn-out tools, insufficient lubrication, scratches on the steel surface and burr compromise the quality of the cold forming process.

Table 5. Ruukki structural steels. Minimum bending radius and comparison of different steels in terms of bendability Bending angle $\leq 90^\circ$. Bending in all directions vs. rolling direction of the steel plate

Steel grade	Minimum allowed internal bending radius at nominal thicknesses, mm														
	≤ 2.5	>2.5 ≤ 3	>3 ≤ 4	>4 ≤ 5	>5 ≤ 6	>6 ≤ 7	>7 ≤ 8	>8 ≤ 10	>10 ≤ 12	>12 ≤ 14	>14 ≤ 16	>16 ≤ 18	>18 ≤ 20	>20 ≤ 25	>25 ≤ 30
Ruukki Laser, sheets															
Ruukki Laser 250 C	1.5	1.5	2	2.5	3	5	5.5	7	8.5	10	11.5	-	-	-	-
Ruukki Laser 355 MC	0.5	0.7	1	1.5	2	3.5	4	5	6	7	8	-	-	-	-
Ruukki Laser 420 MC	1.2	1.5	2	2.5	3	5.5	6.5	8	9.5	11	-	-	-	-	-
Ruukki Laser, heavy plates															
Ruukki Laser 250 C	-	-	-	-	-	-	-	12	12	14	16	18	20	25	30
Ruukki Laser 355 MC	-	-	-	-	-	-	-	9.5	9.5	11.5	13	14.5	16	-	-
Ruukki Laser 420 MC	-	-	-	-	-	-	-	12	12	14	16	18	20	-	-
Optim, sheets															
Optim 500 MC	2	2.5	3	4	4.5	7	8	10	12	-	-	-	-	-	-
Optim 550 MC	2	2.5	3.5	4.5	5.5	8	9	11	-	-	-	-	-	-	-
Optim 550 W	-	1.5	2	2.5	3	3.5	4	-	-	-	-	-	-	-	-
Optim 600 MC	2.5	2.5	3.5	5	7	9	10	12	-	-	-	-	-	-	-
Optim 650 MC	2.5	3	4	6	8	10	12	14	-	-	-	-	-	-	-
Optim 700 MC	-	3.5	5	6	8	12	14	16	-	-	-	-	-	-	-
Optim 700 MC Plus	-	3	4	5	6	7	8	10	18	-	-	-	-	-	-
Optim 900 QC	8	9	12	15	19	24	24	-	-	-	-	-	-	-	-
Optim 960 QC	9	10.5	14	17.5	22	28	28	-	-	-	-	-	-	-	-
Optim 960 W	9	10.5	14	17.5	22	28	28	-	-	-	-	-	-	-	-
Optim 1100 QC	10	12	16	20	25	32	-	-	-	-	-	-	-	-	-
Optim, heavy plates															
Optim 500 ML	-	-	-	-	-	-	9.5	12	14.5	17	19	21.5	24	-	-
Optim 700 QL	-	-	-	-	18	21	24	30	36	42	48	54	60	-	-
Steel grade															
Minimum allowed internal bending radius at nominal thicknesses, mm															
	≤ 2.5	>2.5 ≤ 3	>3 ≤ 4	>4 ≤ 5	>5 ≤ 6	>6 ≤ 7	>7 ≤ 8	>8 ≤ 10	>10 ≤ 12	>12 ≤ 14	>14 ≤ 16	>16 ≤ 18	>18 ≤ 20	>20 ≤ 25	>25 ≤ 30
Multisteel, sheets and heavy plates plus Multisteel N, heavy plates															
Multisteel and Multisteel N	4	5	6	8	10	12	16	20	24	28	32	36	40	50	60
Weather-resistant steels, sheets and heavy plates															
COR-TEN® A	6	6	8	10	12	21	24	30	36	42	-	-	-	-	-
COR-TEN® B	6	6	8	10	12	21	24	30	36	42	48	54	60	-	-

Table 6. Standard structural steels manufactured by Ruukki Minimum bending radius and comparison of different steels in terms of bendability. Bending angle $\leq 90^\circ$. Bending in all directions vs. rolling direction of the steel plate

Steel grade	Minimum allowed internal bending radius at nominal thicknesses, mm														
	≤ 2.5	>2.5 ≤ 3	>3 ≤ 4	>4 ≤ 5	>5 ≤ 6	>6 ≤ 7	>7 ≤ 8	>8 ≤ 10	>10 ≤ 12	>12 ≤ 14	>14 ≤ 16	>16 ≤ 18	>18 ≤ 20	>20 ≤ 25	>25 ≤ 30
Multisteel, sheets and heavy plates plus Multisteel N, heavy plates															
Multisteel and Multisteel N	4	5	6	8	10	12	16	20	24	28	32	36	40	50	60
EN 10025-3 standard steels, sheets and heavy plates															
S235JRC	2.5	3	6	8	10	12	16	20	25	28	32	40	45	55	70
S355J2C	4	5	8	10	12	16	20	25	32	36	40	50	63	75	90
EN 10025-3 standard steels, sheets and heavy plates															
S355N and 355NL	6.3	7.5	10	12.5	15	17.5	20	25	30	35	40	45	50	62.5	75
S420N and 420NL ¹⁾	-	-	-	-	30	35	40	50	60	70	80	90	100	-	-
EN 10025-4 standard steels, sheets and heavy plates															
S355M and 355ML	6.3	7.5	10	12.5	15	17.5	20	25	30	35	40	45	50	-	-
S420M and 420ML ²⁾	-	-	-	-	30	35	40	50	60	70	80	90	100	-	-
S460M and 460ML ²⁾	12.5	15	20	25	30	35	40	50	60	70	80	90	100	-	-
EN 10149-2 standard steels, sheets and heavy plates															
S355MC	0.7	0.8	2	2.5	3	7	8	10	12	14	16	18	20	-	-
S500MC ³⁾	2.5	3	6	7.5	9	14	16	20	24	-	-	-	-	-	-
S700MC ³⁾	-	4.5	8	10	12	17.5	20	25	-	-	-	-	-	-	-

¹⁾ The S420N and S420NL steel grades are delivered as heavy plates only.

²⁾ Delivered mainly as heavy plates, but the S460M steel grade as sheets, too.

³⁾ The S500MC and S700MC steel grades are delivered as sheets only.

Table 7. Raex wear-resistant steels. Minimum bending radius transversely and longitudinally. Bending angle $\leq 90^\circ$

Steel grade	Minimum allowed internal bending radius at nominal thicknesses, mm													
	≤ 2.5	>2.5 ≤ 3	>3 ≤ 4	>4 ≤ 5	>5 ≤ 6	>6 ≤ 7	>7 ≤ 8	>8 ≤ 10	>10 ≤ 12	>12 ≤ 14	>14 ≤ 16	>16 ≤ 18	>18 ≤ 20	
Raex, sheets and heavy plates														
Raex 300 ^{1) 2)}	7.5	9	12	15	18	21	24	-	-	-	-	-	-	-
Raex 400 ¹⁾	7.5	9	12	15	18	21	24	30	36	42	48	54	60	-
Raex 400 ²⁾	10	12	16	20	24	28	32	40	48	56	64	72	80	-
Raex 450 ¹⁾	10	12	16	20	24	28	32	40	48	56	64	72	80	-
Raex 450 ²⁾	12.5	15	20	25	30	35	40	50	60	70	80	90	100	-
Raex 500 ¹⁾	-	15	20	25	30	35	40	50	60	70	80	90	100	-
Raex 500 ²⁾	-	18	24	30	36	42	48	60	72	84	91	108	120	-

¹⁾ Bending line vs. rolling direction (of the steel plate) transversely.

²⁾ Bending line vs. rolling direction (of the steel plate) longitudinally.

• Occupational safety

Special care must be taken in all stages of handling of hardened steels. Flanging is challenging due to the high strength and high flexural stresses of the plate. If the bending radius, for example, is too small and a crack is created in the bending point, the plate may fly from the bending tool in the direction of the bend. Those bending the plate must take appropriate precautions to protect themselves and no outsiders must be allowed in the area. The safest location is usually by the bending machine. The handling instructions of the steel supplier and safety instructions of the workshop must be adhered to in detail. New employees must receive appropriate training before they are allowed to process hardened steels.

**Ruukki provides its customers
with energy-efficient steel
solutions for better living,
working and moving.**

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