8. Temperature effects on the fastening

8.1 Effect of low temperatures on fasteners

Steel tends to become more brittle with decreasing temperature. Increased development of natural resources in Arctic regions has led to the introduction of steels that are less susceptible to brittle failure at subzero temperatures. Most siding and decking fasteners are used to fasten the liner sheets of an insulated structure and are not exposed to extremely low temperatures during service. Examples of situations where the fastenings are exposed to extremely low temperatures during their service life are:

- Fastenings securing cladding in single-skin construction
- Construction sites left unfinished over a winter
- Liner sheets in a cold-storage warehouse

Low temperature embrittlement

The susceptibility of fasteners to become brittle at low temperatures can be shown by conducting impact bending tests over a chosen temperature range. The ability of Hilti drive pins to remain ductile over a temperature range from +20°C to –60°C is shown clearly by the fact that the impact energy required remains nearly constant throughout this temperature range.

Impact bending test - DSH57 (4.5 mm diameter, HRC 58 ± 1)

Temperature		Impact energy (foot-pounds)			Impact energy (Joules)		
°F	°C	minimum	maximum	mean	minimum	maximum	mean
68	20	35.1	>36.1	>36.1	47.6	>48.9	>48.9
32	0	35.8	>36.1	36.0	48.5	>48.9	48.8
– 4	–20	31.4	>36.1	34.3	42.6	>48.9	46.5
–40	–40	34.4	36.5	35.7	46.6	49.4	48.4
–76	–60	35.6	36.2	35.9	48.2	49.0	48.7

Impact bending test - X-CR (4.0 mm diameter)

Temperature		Impact energy (foot-pounds)			Impact energy (Joules)		
°F	°C	minimum	maximum	mean	minimum	maximum	mean
68	20	14.8	17.0	15.9	20	23	21.6
32	0	17.7	15.5	18.3	24	21	24.8
– 4	–20	14.8	15.9	15.5	20	21.6	21.0
–40	–40	16.2	17.9	16.8	21.9	24.2	22.8
–76	–60	14.2	15.6	15.1	19.2	21.1	20.5

Impact bending test - X-CR (3.7 mm diameter)

Temperature °F	°C	Impact energy (foot-pounds) minimum	maximum	mean	Impact energy (Joules) minimum	maximum	mean
68	20	11.5	14.8	13.2	15.6	20.0	17.9
32	0	12.9	16.3	15.1	17.5	22.1	20.4
– 4	–20	13.1	15.8	14.7	17.8	21.4	19.9
–40	–40	14.2	15.8	14.8	19.2	21.4	20.1
–76	–60	12.3	15.0	13.7	16.7	20.3	18.6

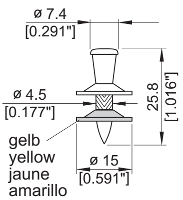
Tests conducted according to DIN EN 10045 parts 1–4
Distance between supports = 22 mm
The symbol ">" indicates no breakage of the specimens. In the other cases, about 50% of the specimens suffered breakage.

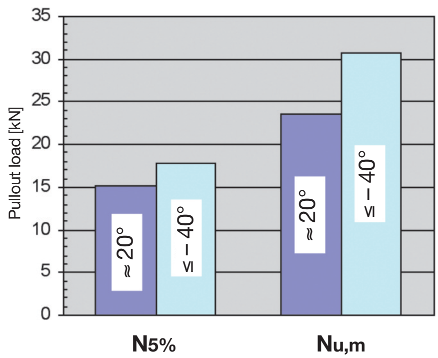
8.2 Effect of low temperatures on fastenings to steel

Effect of low temperatures on pull-out strength

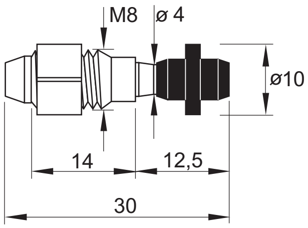
Tests show that very low temperatures tend to increase pull-out strength with both standard zinc-plated fasteners and with the stainless steel. The results of two tests are summarized below. The fasteners were driven at room temperature and tested at –40°C to –70°C. A control sample was tested at 20°C. Explanations for the greater strength at low temperatures include increase in the strength of the zinc that is displaced into the knurling as well as increased strength of the fusing at the point of the fastener.

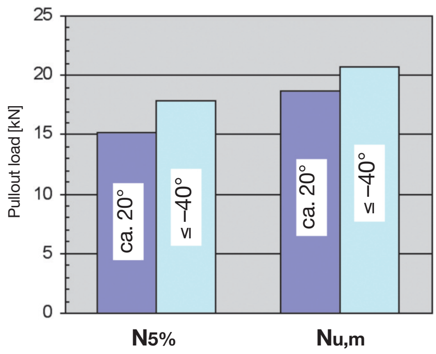
Base steel:	S355K2G3
	h = 25 mm
	$\mathbf{f_y}$ = 402 MPa
	$\mathbf{f_u}$ = 538 MPa
Fastened material:	sheet steel, 2 x 1 mm
Tool:	DX 750
Fastener:	ENPH2-21 L15





Base steel : **h** = 20 mm
f_u = 450 MPa
Fastened material : none
Tool : DX 750 G
Fastener : X-CRM8-15-12 FP10





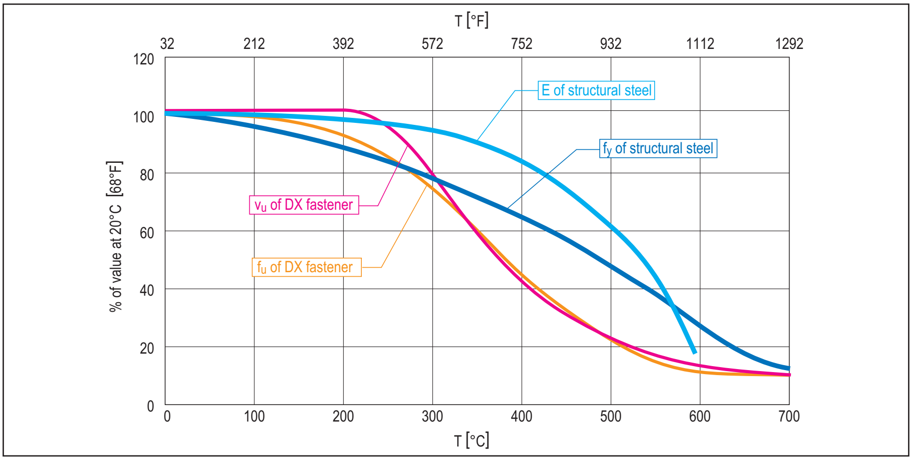
Two facts stand out from this testing:

- **Pull-out strength increased as temperature decreased**
- **Pull-out from the base steel was the only mode of failure observed. There were no fractures!**

8.3 Fire rating of fastenings to steel

Standard zinc-plated, thermally hardened steel fasteners

When subjected to high temperatures as in a fire, both powder-actuated fasteners and structural steel lose strength. Data for standard zinc-plated, thermally hardened fasteners and structural steel are plotted in the graph below.



Up to about 300°C [572°F], the strength loss for DX fasteners is roughly proportional to the yield strength loss of structural steel. At 600°C [1112°F], DX fasteners have about 12% of their 20°C [68°F] strength left and structural steel about 26%. Since DX fasteners obtain their high strength through a thermal hardening process, the loss in strength at elevated temperatures is proportionally greater than for structural steel.

The relevance of different strength losses has to be evaluated in the context of the proportion of the material strengths that are actually exploited in a design. In a design calculation, it is conceivable that some steel will actually reach yield stress.

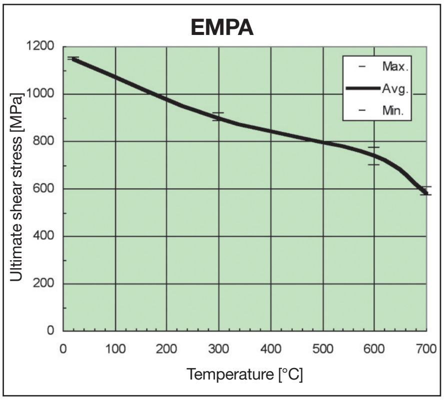
The material strengths of an X-ENP-19 L15 fastener is 30 kN [6.74 kips] in tension and 18.6 kN [4.18 kips] in shear respectively.

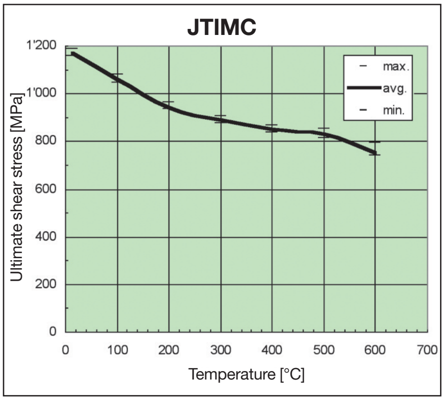
The recommended working load in tension and shear for an X-ENP-19 L15 16 gauge (1.5 mm) fastening is 4.7 kN [1.057 kips] in tension and 4.6 kN [1.034 kips] in shear, respectively. Thus, the exploitation of the X-ENP-19 L15 strength at about 600°C is only 16 to 25% compared to about 74% for structural steel.

In a fire, powder-actuated fastenings will not be the governing factor. If the fire protection requirements permit the use of structural steel, then powder-actuated fastening can also be used without negative impact on fire protection.

CR500 stainless steel fasteners

Hilti X-CR/X-CRM fasteners are much more resistant to loss of strength at high temperatures than standard fasteners. The effect of temperature on ultimate shear stress of X-CR/X-CRM/X-BT fasteners was determined in single lap joint shear tests by the Swiss Federal Laboratory for Materials Testing and Research (EMPA). The results are plotted in the diagram below. This test was done by shearing 4.5 mm diameter fasteners that were inserted in steel plates with 4.6 mm diameter drilled holes.





In Japan, similar tests were carried out by JTICM (Japan). These tests were done by driving a 4.5 mm diameter X-CR nail through a 6 mm steel plate into a second 6 mm thick steel plate and shearing the two plates. From the graph it is apparent that the results are nearly the same.

At 600°C, the CR500 material has 64% of its 20°C shear strength left. By comparison, standard fasteners have only 12% and structural steel only about 26%. The excellent fire resistance of the CR500 material alone justifies its use for some applications.

8.4 Fire rating of fastenings to concrete

Concrete is weakened and damaged by fire but not as quickly as steel. In ISO-standard fire tests conducted with DX-Kwik fastenings at the Braunschweig Technical University in Germany the only failure mode was fracture of the nails.

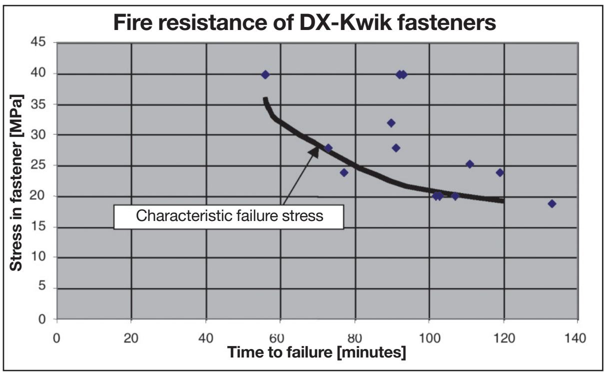
The actual test data are shown in the table below:

X-DKH 48 P8S15 DX-Kwik fastener, 4.0 shank

Tested in crack width ΔW (mm)	Tensile load, **F** (N)	Fire resistance/ time to failure (minutes)	Failure mode
0.2	250	103	Nail fracture
0.2	250	107	Nail fracture
0.2	350	73	Nail fracture
0.2	350	91	Nail fracture
0.2	500	56	Washer pullover
0.2	500	92	Nail fracture
0.2	500	93	Nail fracture

The stress in the fasteners at failure was calculated and plotted so that a plot of stress versus time resulted.

The characteristic failure stress curve from the previous graph can be used to calculate the failure load for various shank diameters with exposure to fire of different lengths of time. The calculated failure loads for 3.7, 4.0 and 4.5 mm shank diameter fasteners after 60, 90 and 120 minutes exposure to fire are shown in the table below.



Failure loads for various shank diameters and fire exposure times

Shank diameter (mm)	Fire exposure time and failure stress		
	60 minutes 32.1 MPa	90 minutes 22.3 MPa	120 minutes 19.1 MPa
3.7	340 N	240 N	200 N
4.0	400 N	280 N	240 N
4.5	510 N	350 N	300 N

This table can be used to determine recommended loads for the ISO fire resistance required.