TECHNotes

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Metallographic Preparation of Fasteners; Hardness testing evaluation

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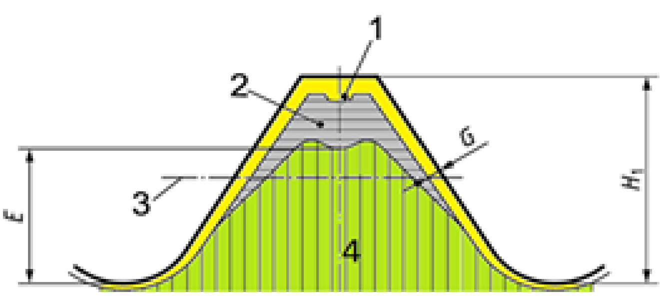
Introduction

Standards are available for guidance on how to assess fasteners with respect to carburisation and decarburisation phenomena. De/carburisation assessment can be investigated microscopically, or through hardness testing as prescribed in EN ISO 898, ASTM F2328M or ASTM E1077, ASTM F606/ and ISO 3887. Before carburisation and decarburisation assessment is carried out, metallographic preparation of the threaded component must be carried out correctly and as close as possible to the longitudinal threaded axis. This involves sectioning, mounting in an appropriate resin to preserve the edges or outermost surface regions, then through a series of grinding and polishing stages before final optical and/or hardness testing analysis is carried out, a detailed preparation guideline can be found on our solutions page titled "Metallographic preparation of fasteners; microscopic assessment".

This application article will highlight metallographic preparation approach that would ensure correct and routine carburisation and decarburisation assessment of steel fasteners using a hardness indentation technique. Hardness evaluation is based on assessment of different zones of de/carburisation as illustrated below and the methodology allows the determination of the height of the base metal zone (E) and the detection of



1....Complete Decarburisation
2....Partial/Ferritic Decarburisation
3....Pitch Line
4....Base Metal
E....Height of non-carburised thread zone
G....Depth of complete decarburisation in thread
H_1....External thread height in the maximum metal condition

Figure 1. *Schematic illustration of de/carburisation zones on threaded components*

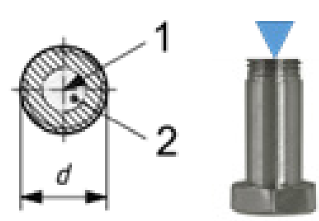
Hardness testing

Routine Hardness Evaluation

For fastener components that can not be tensile tested, hardness testing evaluation is carried out to validate the heat treatment process and that the desired hardness does not surpass the maximum hardness permissible on the fastener. If components have hardness above the maximum permissible level, component embrittlement would occur. Routine hardness checks should be carried out on a suitable surface or on a transverse section through the threaded component. Hardness testing can be carried out using Vickers, Brinell or Rockwell hardness testing as per ASTM/ISO standards.

Cross-sectional hardness evalution

For transverse section of the threaded component, hardness testing should be carried out as illustrated in Figure 2 within the half radius area. The standards specify a minimum load of 10 kilogram indentation force.



1. Axis of the fastener
2. Half radius area with a radius of 0.25 d
3. ASTM F606 specifies a minimum of 3 readings for routine testing.

Figure 2. *cross section hardness indentation*

Hardness on the surface

Hardness should be carried out on the flat surface of the head, or on the end of the fastener or on the unthreaded shank after removal of any plating or other coating and after suitable preparation of the test specimen. This should be done for routine analysis as illustrated in figure 3.

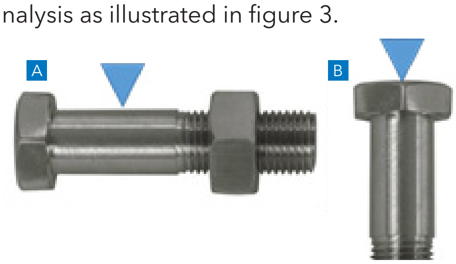


Figure 3. *(a) unthreaded shank, (b) head region*

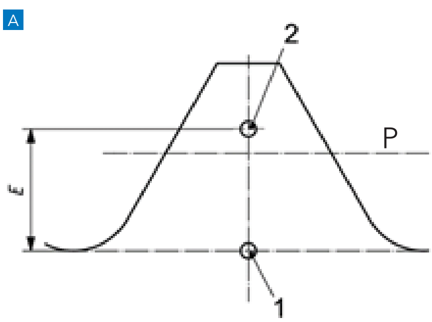
Conformity testing using the rockwell test scale is as described in figure 3 and illustrated below, figure 4 as tested on Buehler's Rockwell 574 tester.

Hardness values;
- Average Rockwell value is about 40HRC for the test piece
- Typical hardness of carburized fasters range from 35 – 40 HRC

***Figure 4**. (c) test piece and indentation points, (d) Rockwell 574*

Decarburization check (ISO/ASTM)

This is conducted to check if the surface of quenched and tempered fasteners is decarburised and to determine the depth of the decarburised zone. Hardness methodology allows one to determine the height of the base metal zone and the detection of partial decarburization by micro-hardness. This methodology is applicable to fasteners with a pitch greater than or equal to 1.25mm. Surfaces do not need to be etched or removal of any protective coating applied on the fastener. ASTM/ISO standards specify regions within the thread that would be hardness checked, Figure 5 with ISO recommending using 0.3-kilogram indentation force, whereas for ASTM, either vicker or knoop testing is applicable with load selection based on the thread pitch (see appendix).



Notes;
- E – height of non-decarburised zone in the thread
- 1 and 2 - measurement points (1 – is reference point)
- P – Pitch line
- Decarburization – HV (2) ≤ HV (1) - 30

***Figure 5**. is a schematic illustration of decarburisation hardness test points*

Decarburisation during heat treatment process causes the loss of carbon resulting in microstructures that have lower hardness compared to the desirable harder carbon rich microstructure, martensite. Standards specify the external thread height values (H1) based on the fastener pitch dimension (P) and what would be the approximate height of the non-carburised thread zone E. Figure 6 illustrates the various measurement components on a threaded fastener.

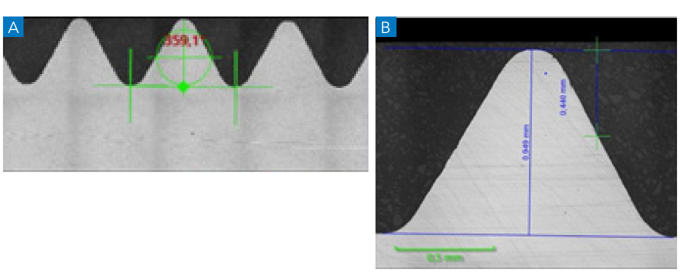
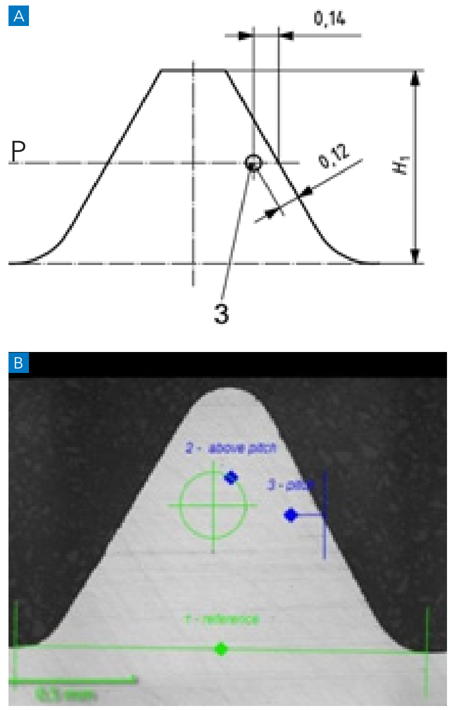


***Figure 6**. (a) illustrates threaded fastener, (b) illustrating tooth dimension with H of 0.950mm equating to a pitch of at least 1.5mm*

Decarburisation is observed when the hardness value at point 2 is less than or equal to the hardness value at point 1 less 30 vickers units.

Carburization check (ISO/ASTM)

Hardness testing is also conducted on fasteners after carburisation process to confirm that they conform to desired hardness specification and that the maximum hardness desired is not exceeded. This is carried out on the threaded region around the pitch line approximately 0.12mm from the surface. A highly carburised region results in surface embrittlement, which subsequently affects the fatigue resistance of the threaded component. Carburisation can also be assessed on longitudinal sections or through surface hardness testing.



Notes;
- 3 - measurement point
- P – Pitch line
- Carburization – HV (3) ≤ HV (1) + 30

HV(1) in Figure 5

Notes;
Hardness value at point 3 for decarburization assessment should not be greater that hardness value at point 1 plus 30 vickers points.

***Figure 7**. (a) schematic illustration of carburisation hardness test point, (b) illustrating the test points 1, 2 (decarburisation) and 3 (carburisation)*

De/carburization check

An alternative evaluation is to conduct a series of indentations from the crest of the thread traversing towards the core region of the thread. The results of the test would show hardness variation from the surface to the core region. This would be an ideal way to highlight considerable change in hardness with respect to the core hardness. Similarly, a series of indentation can also be carried out at the pitch level with indentations running perpendicular to the surface as illustrated in Figure 8. In this example, a Vickers indentation method has been used with indentation spacing set at 0.120mm from the surface and with respect to each indent.

The limits relating to core hardness minus or plus 30 Vickers/Knoop for decarburisation and carburisation assessment can be included in the test program. When those limits are breached, there is a pictorial chart illustrating whether de/carburisation limits have been surpassed.

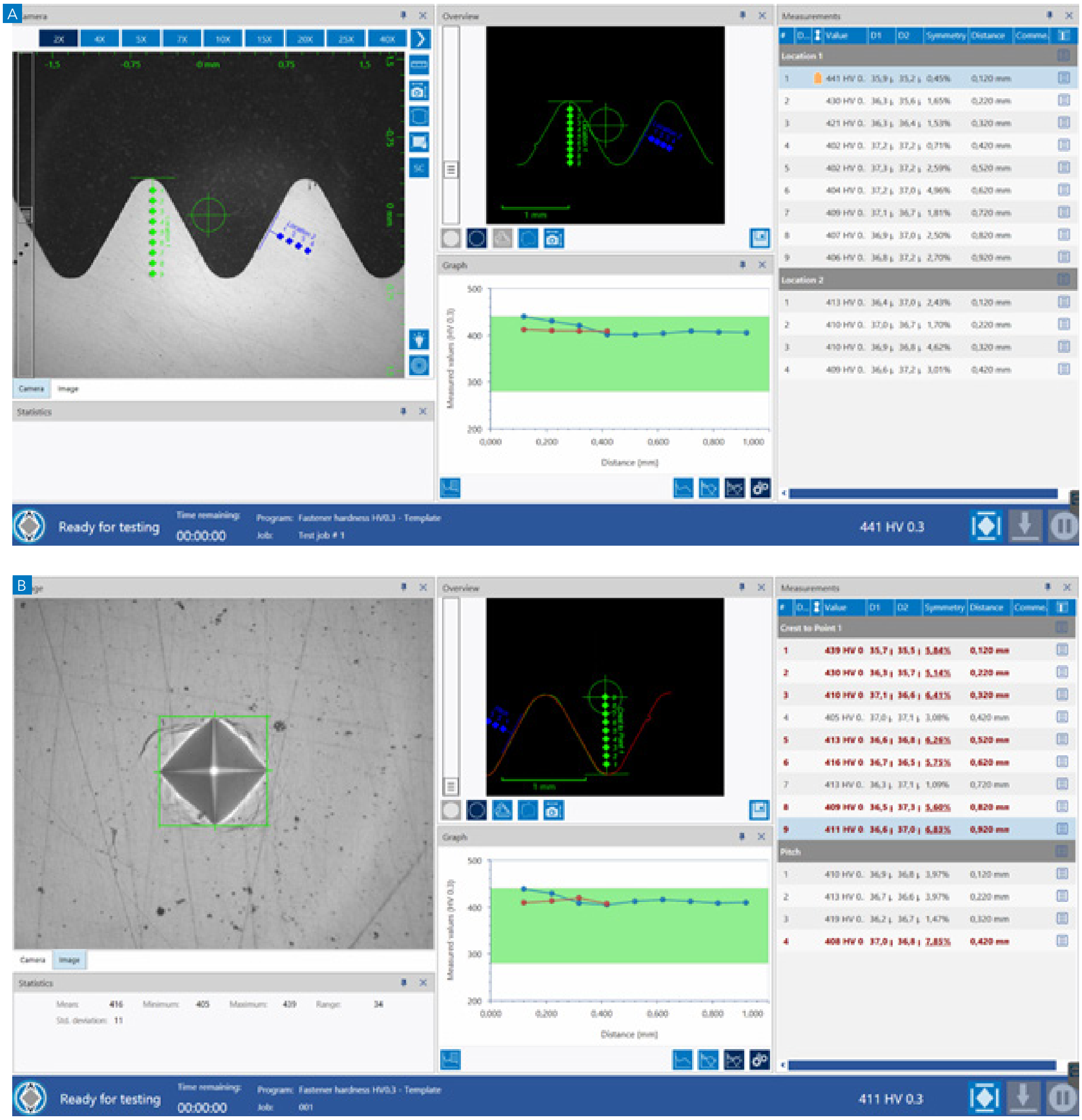


Figure 8. (a) showing indentation from the crest to the core regions, (b) showing indentations carried out with the aid of templates to speed up testing process.

Retempering check

A retempering check is conducted to ensure that the minimum tempering temperature was achieved during the heat treatment process. ISO specifies that this check is conducted in case of a dispute/arbitration. The test involves retempering the fastener, holding it for 30 minutes at a part temperature of 10°C less than the minimum tempering temperature. Then using Vickers hardness testing to take three new reading on the same fastener and in the same area as for the first determination. The mean is then taken before and after retempering and compared. A reduction in vickers hardness values, if any, should be less than 20 vickers units.

Appendix

Terminologies

Base metal hardness – hardness closest to the surface (when traversing from core to outside diameter) just before an increase or decrease occurs, denoting carburization or decarburization, respectively

Decarburisation – is the loss of carbon form the surface layer of the fastener to a level below the solubility limit of carbon in ferrite so that only ferrite is present.

Complete/Gross decarburisation – also known as complete decarburisation where there is sufficient carbon loss from the steel leaving a clearly defined ferritic grains after microscopic analysis.

Partial decarburisation - decarburization with sufficient loss of carbon to cause a lighter shade of tempered martensite and a significantly lower hardness than that of the adjacent base metal, without, however, showing ferrite grains under metallographic examination

Ferritic decarburisation - decarburization with considerable loss of carbon to cause a lighter shade of tempered martensite, with the presence of ferrite grains or grain boundary network under metallographic examination.

ASTM Guidelines

Thread Pitch, mm	Load	
	Knoop (HK)	Vickers (HV)
Over 0.60	500 gf	300 gf
0.45 through 0.60	200 gf	200 gf
Less than 0.45	100 gf[A]	100 gf[A]

[A] Lighter loads shall be used if the size of the part warrants.

Microindentation hardness load vis-à-vis pitch diameter when using vickers or knoop indenter

Class	N	G max	Typical Applications
1	½ H	0.015 mm	For heat treated products which have tensile strengths up to 830 MPa and those with a specified minimum tensile strength of 830 MPa or a hardness range of 24 to 34 HRC, or both.
2	⅔ H	0.015 mm	For products with a minimum tensile strength of 1040 MPa or a hardness range of 33 to 39 HRC, or both.
3	¾ H	none permitted	For products with a minimum tensile strength of 1200 MPa or a minimum specified hardness of 37 HRC, or both.
4	¾ H	none permitted	For products with a recessed socket drive of a minimum tensile strength of 980 MPa, a specified hardness range within 38 to 53 HRC or manufactured to the ASTM requirements of Specifications A574M, F835M, or F912M, or both.
5	⅔ H	0.015 mm	For heat treated nuts with a hardness of 24–38HRC

Classes of decarburisation

ISO Guidelines

		Property class									
		4.6	4.8	5.6	5.8	6.8	8.8	8.8 (cont.)	9.8	10.9	12.9/ 12.9
Vickers hardness, HV $F \geqslant 98$ N	min.	120	130	155	160	190	250	255	290	320	385
	max.	220 g				250	320	335	360	380	435
Brinell hardness, HBW $F = 30 D^2$	min.	114	124	147	152	181	238	242	276	304	366
	max.	209 g				238	304	318	342	361	414
Rockwell hardness, HRB	min.	67	71	79	82	89	—				
	max.	95,0 g				99,5	—				
Rockwell hardness, HRC	min.	—					22	23	28	32	39
	max.	—					32	34	37	39	44
Surface hardness, HV 0,3	max.	—					h			h, i	h, j
Height of non-decarburized thread zone, E, mm	min.	—					$\frac{1}{2} H_1$			$\frac{2}{3} H_1$	$\frac{3}{4} H_1$
Depth of complete decarburization in the thread, G, mm	max.	—					0,015				
Reduction of hardness after retempering, HV	max.	—					20				

Mechanical and physical properties of bolts, screws and studs (Iso 898-1)

Notes;
g - Hardness determined at the end of a fastener shall be 250 HV, 238 HB or 99,5 HRB maximum.
h - Surface hardness shall not be more than 30 Vickers points above the measured core hardness of the fastener when determination of both surface hardness and core hardness are carried out with HV 0.3
i - Any increase in hardness at the surface which indicates that the surface hardness exceeds 390 HV is not acceptable
j - Any increase in hardness at the surface which indicates that the surface hardness exceeds 435 HV is not acceptable

Appendix

ISO Guidelines

Dimensions in millimetres

Pitch of thread P[a]			0,5	0,6	0,7	0,8	1	1,25	1,5	1,75	2	2,5	3	3,5	4
		H_1	0,307	0,368	0,429	0,491	0,613	0,767	0,920	1,074	1,227	1,534	1,840	2,147	2,454
Property class	8.8, 9.8	E_{min}[b]	0,154	0,184	0,215	0,245	0,307	0,384	0,460	0,537	0,614	0,767	0,920	1,074	1,227
	10.9		0,205	0,245	0,286	0,327	0,409	0,511	0,613	0,716	0,818	1,023	1,227	1,431	1,636
	12.9/12.9		0,230	0,276	0,322	0,368	0,460	0,575	0,690	0,806	0,920	1,151	1,380	1,610	1,841

[a] For P < 1,25 mm, microscopic method only.

[b] Calculated on the basis of the specification in Table 3, No. 14.

Values for height of externalthread in maximum material condition, H1, and minimum height of non-decarburised zone in thread, E_{min}

Useful References

SumMet, B. (2018). The Science Behind Materials preparation. Waukegan, Illinois, U.S.A. Retrieved from https://www.buehler.com/literature.php

SumMet, B. (2015). Fastener metallography for today, Waukegan, Illinois, U.S.A. Retrieved from https://www.buehler.com/literature.php

NPCS Board of Consultants & Engineers. The Complete Technology Book on Steel and Steel Products (Fasteners, Seamless Tubes, Casting, Rolling of Flat Products & others)

ASTM standards; E1077, A370, E3, E384, E407 F2328, F2328M, F606/M

ISO standards; 898-1, 898-1, 4042, 6507, 6506, 6508

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