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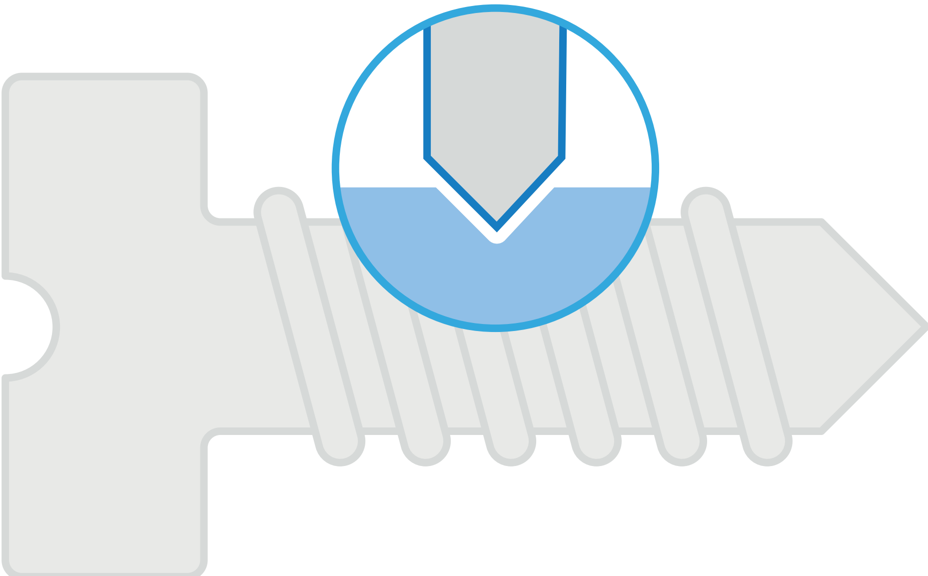

Metallic Hardness Measurement Fasteners and Hardware

White Paper

Metallic Hardness Measurement Fasteners and Hardware

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METALLIC HARDNESS MEASUREMENT FASTENERS

Preface

The subject of hardness and hardness measurement practice is, simply said, a mature technology.

This paper will discuss about hardness measuring techniques and the application at fasteners. We will not deal with dynamic hardness, compatibility between hardness and tensile strength or the resultant hardness relative to differing tempering processes.

This paper will provide a glimpse of the prevailing practices in the fastener industry. And, share the experiences in the hope that the use of material hardness results will be used in an appropriate manner.

METALLIC HARDNESS MEASUREMENT FASTENERS

Hardness

Hardness is the resistance of a material to permanent deformation or indentation. There are several hardness methods, using differing indentation that give rise to hardness values of materials.

Historically, the popularity of hardness testing took off with the onset of the automobile industry. The intention is related to deliverable quality consistency. The advantages of hardness testing are, quick and easy, finished parts can be tested and used since it is a non-destructive test and almost any shape and size of specimen can be tested. The other reason is that the cost of hardness testing is relatively inexpensive.

Mechanical hardness tests make use of a specifically shaped indenter, significantly harder than the test sample that is pressed into the surface of the test piece using a specific force. Either the depth or size of the indent is measured to determine a hardness value depending on the method used.

A common use of hardness test is at heat treatment process to determine product properties after and process management.

In the early hardness test method, there are 2 main techniques:

1. A known or constant weight to cause a measureable resultant indentation or depth
2. Variable weight to cause a fixed indentation or depth.

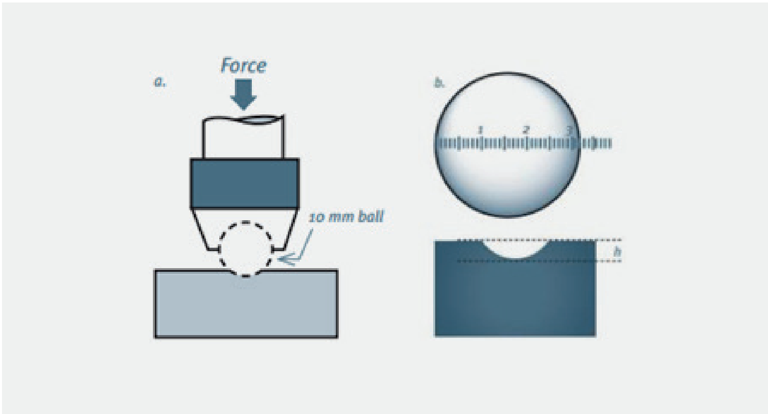
There are a few major hardness scales, they are:

- Brinnel - HB
- Rockwell - HR
- Vickers - HV

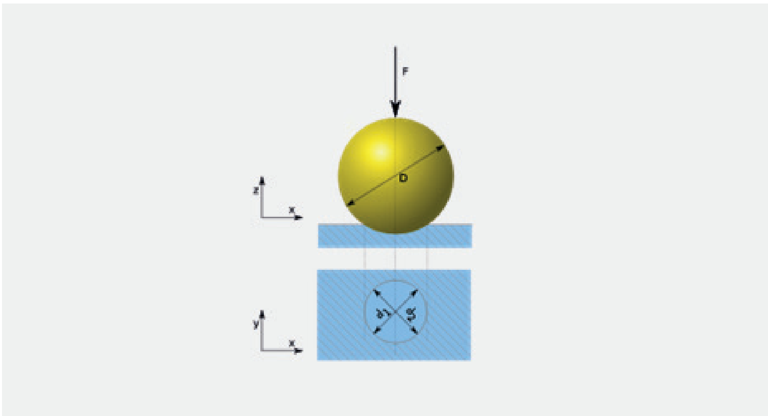
Each involve the use of a specifically shaped diamond, carbide or hardened steel indenter pressed into the material with a known force using a defined test procedure. The hardness values are determined by measuring either the depth of indenter penetration or the size of the resultant indent – the smaller the indent, the harder the materials, the higher the hardness number. The hardness values must also be reported with the proper test scale symbol, HB, HK, HR, etc.

Hardness conversion tables are available with empirical relationship between the known hardness measuring techniques, at some points interpolated. Hardness conversion tables unlike converting from inch to metric units, there is no direct mathematical correlation between hardness units. Use the stipulated method. The conversion tables must be used as a last resort and, with caution. Hopefully, the below description of each method will help to enlighten.

The Brinell Ball Test was most popular back in the early 1900s. The technique used is to press a hard ball into material under test with a known load. Various hardness measurements are method dependent and every test result must have a label identifying the test method used. An example of a traditional specification for Brinell hardness is HB50. The resultant ball with known force causing an indent is then measured and hardness determined. The current new standard is for example 600 HBW 1/30/15 according to EN ISO 6506-1 where:

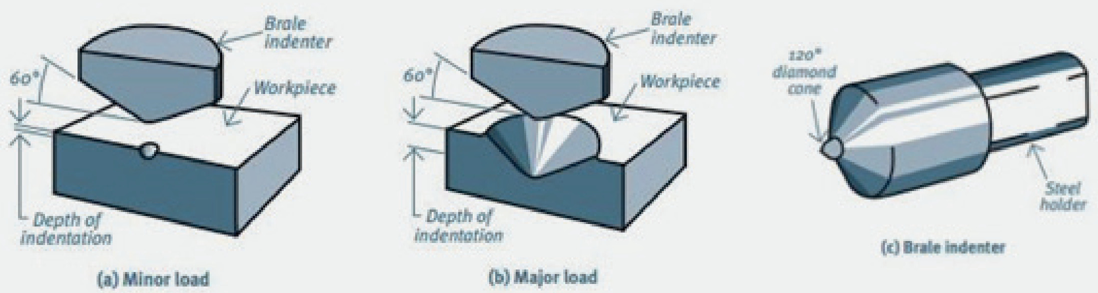


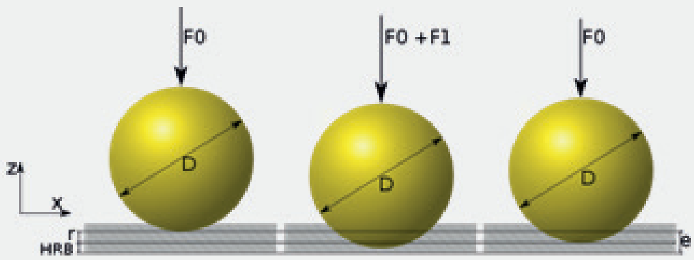
600	Brinnel hardness value
HB	Hardness symbol
W	Indenter type; tungsten carbide
1	Ball diameter in mm
30	Kgf applied force
15	Duration of test force in sec



The Rockwell Hardness method is to apply an initial light load followed by a heavier load with known duration with an indenter. After the heavier load is removed with the light load remaining, the difference in depth is deemed the Rockwell hardness number. Most materials are covered using the Rockwell B (Ball indenter) and C (Cone indenter) scales. The prevailing reference for Rockwell hardness is for example 60HRBW according to EN ISO 6508-1.

60	Rockwell hardness value
HR	Rockwell hardness symbol
B	Rockwell scale symbol
W	Ball type, S for steel, W for tungsten

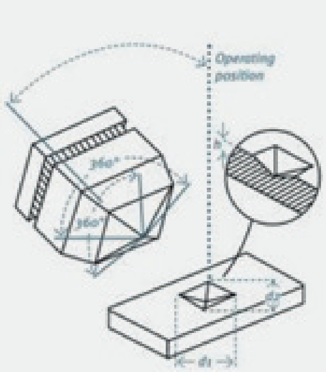


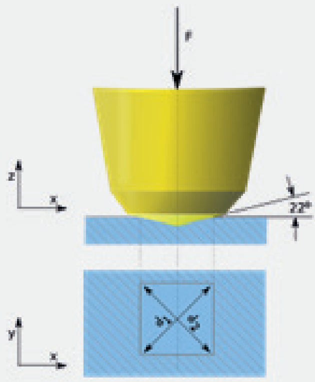


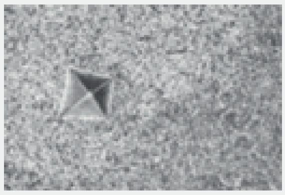
The Vickers and Micro Vickers hardness method make use of a square based pyramid indenter. The Micro Vickers technique is designed for used at small or limited area. For example, the carburized surface of a gear where the surface, core and carburized thickness are tested.

The Vickers technique is used as reference where there is a dispute in hardness results.
The Vickers hardness indication according to EN ISO 6507-1 is for example 640HV30/10 where:

640	Vickers hardness value
HV	Hardness symbol
30	Kgf applied force
10	Duration time in sec







METALLIC HARDNESS MEASUREMENT FASTENERS

Preparation for hardness testing

In order to obtain consistent results, the following check points need to be considered when preparing to conduct hardness testing.

1. Clean test surface.
2. Polished surface where possible and necessary for Micro Vickers.
3. Test sample surface perpendicular to the indenter.
4. Select the right load for the test piece. The larger the dent, the more accurate the results.
5. Dents not too close to the edge. The results will not be accurate or consistent if too close.
6. Care must be taken for thin test pieces. Select the appropriate test method and load.

METALLIC HARDNESS MEASUREMENT FASTENERS

Hardness test at fasteners and hardware

The following are four main fasteners hardware selected as examples to highlight hardness are used as part of the qualitative reference during manufacturing and by end users.

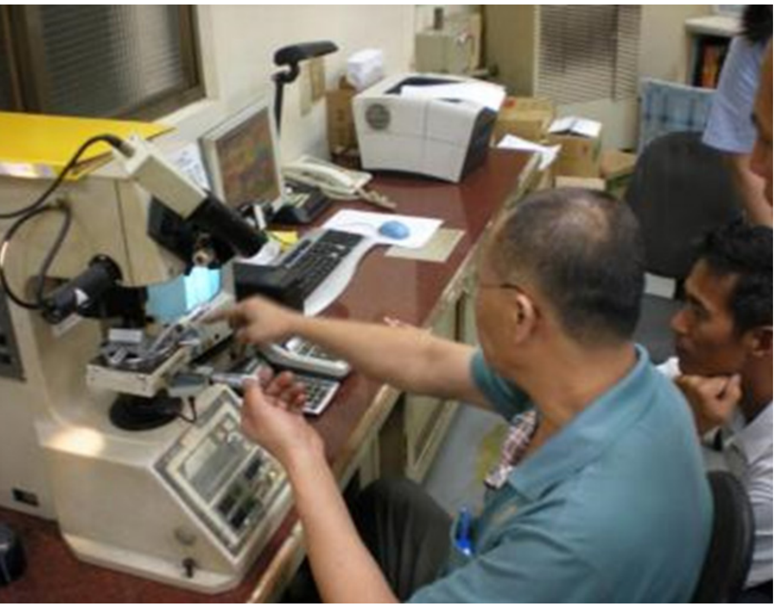
Fastener manufacturing processes

The generic manufacturing processes of most fasteners are indicated below with in-process checks not indicated. Almost all fastener hardware goes through the same processes with some minor differences depending on the raw material, final product and application expectations.

1. Raw material and control.
2. Head forming.
3. Thread rolling.
4. Heat treatment.
5. Finishing.
6. Final Quality Test.
7. Packing.

At heat treatment, this is where hardness test is the primary test applied to manage the process and product outcome. Raw materials at incoming at times do check on hardness in particular high strength fasteners. Some coating finishes require hardness test. The correct hardness technique selected depends on the product type. Often used is the Rockwell hardness test mainly due to its non-destructive method, simplicity and quick result.

Heat treatment of fasteners are often processed before the final product finishing such as electroplating, zinc flake coating, hot dip galvanizing and such. For product finishing that requires heat as a catalyst for during, it has been known that fastener mechanical properties can be altered due to poorly managed thermal energy during processing. Hardness testing can be used as a process control tool.



Bolts and screws

The ISO 898 is one of the more comprehensive standards, mainly metric screws in determining the soundness of fasteners for both manufacturers and end users. Primarily used for homogeneous or through hardened fasteners. It has no less than 19 characteristics that need to be determined. Hardness tests take up 7 of the characteristics including carburization and decarburization defects determination for thread pitch equal to and greater than 1.25 mm. Industry users referencing this standard, would be interesting to note that hardness homogeneity is determined or defined by core hardness and surface hardness difference of no more than 30 Vickers hardness.

Table 3 - Mechanical and physical properties of bolts, screws and studs

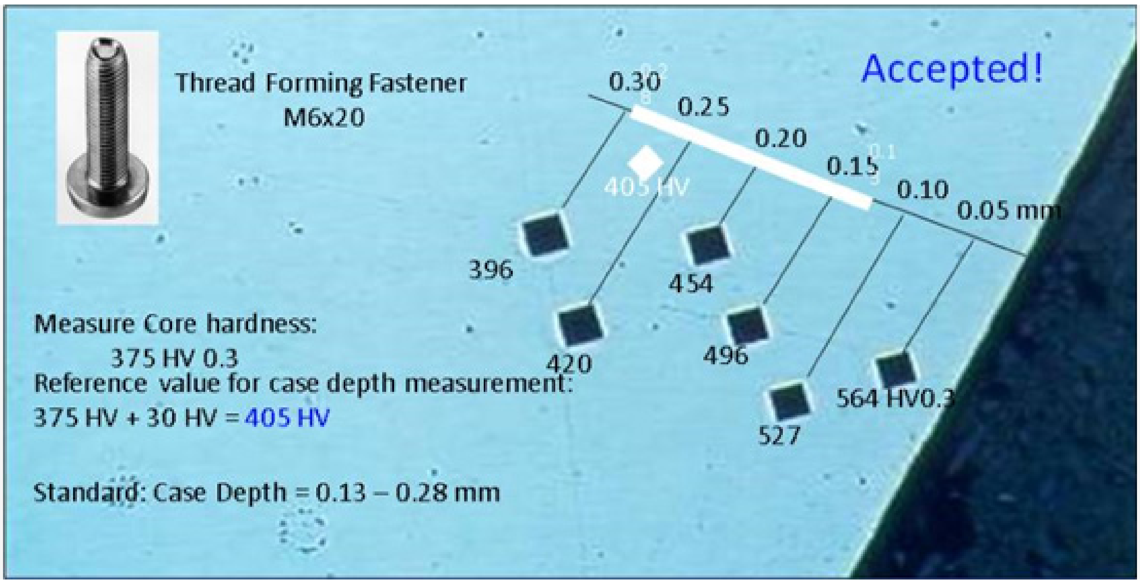
No.	Mechanical or physical property		Property class 4.6	4.8	5.6	5.8	6.8	8.8 d ≤ 16 mm[a]	8.8 d > 16 mm[b]	9.8 d ≤ 16 mm	10.9	12.9
1	Tensile strenght, R_m, MPa	nom.[c]	400		500		600	800		900	1 000	1 220
		min.	400	420	500	520	600	800	830	900	1 040	1 220
2	Lower yield strength, R_{oL}[d], MPa	nom.[c]	240	---	300	---	---	---	---	---	---	---
		min.	240	---	300	---	---	---	---	---	---	---
3	Stress at 0,2% non-proportional elongation, $R_{p0,2}$, MPa	nom.[c]	---	---	---	---	---	640	640	720	900	1 080
		min.	---	---	---	---	---	640	660	720	940	1 100
4	Stress at 0,0048d non-proportional elongation for full-size fasteners, R_{pf}, MPa	nom.[c]	---	320	---	400	480	---	---	---	---	---
		min.	---	340[e]	---	420[e]	480[e]	---	---	---	---	---
5	Stress under proof load, S_p[f], MPa	nom.	225	310	280	380	440	580	600	650	830	970
	Proof strength ratio: $S_{p,nom}/R_{oL,min}$ or $S_{p,nom}/R_{p0,2\,min}$ or $S_{p,nom}/R_{pf,min}$	---	0,94	0,91	0,93	0,90	0,92	0,91	0,91	0,90	0,88	0,88
6	Percentage elongation after fracture for machined test pieces, A, %	min.	22	---	20	---	---	12	12	10	9	8
7	Percentage reduction of area after fracture for machined test pieces, Z, %	min.	---	---	---	---	---	52		48	48	44

No.	Mechanical or physical property		Property class									
			4.6	4.8	5.6	5.8	6.8	8.8	8.8	9.8	10.9	12.9
								d ≤ 16 mm[a]	d > 16 mm[b]	d ≤ 16 mm		
8	Elongation after fracture for full size fasteners, A_t (see also Annex C)	min.	---	0,24	---	0,22	0,20	---	---	---	---	---
9	Head soundness	---	No fracture									
10	Vickers hardness, HV F≥98N	min.	120	130	155	160	190	250	255	290	320	385
		max.	220[g]				250	320	335	360	380	435
11	Brinell hardness, HBW $F=30fx^2$	min.	114	124	147	152	181	245	250	285	316	380
		max.	209[g]				238	316	331	355	375	429
12	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
13	Surface hardness, HV 0,3	max.	---	---	---	---	---	---	---	---	390	435
14	Non-carburization, HV 0,3	max.	---	---	---	---	---	h			h	h
15	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				
16	Breaking torque, Af_g, Nm	min.	---	---	---	---	---	in accordance with ISO 896-7				
17	Impact strenght, K_g^U, J	min.	---	---	27	---	---	27	27	27	27	k
18	Surface integrity in accordance with	---	ISO 6157-1[1]									ISO 6157-3

Thread Forming Screws

In the case for thread forming or thread rolling screws, the mechanical property tests expectations are slightly different from standard bolts and nuts. The ISO 7085 is referenced. The key differences are the measurement of hardness is needed. The "case" of the heat treated case hardening process. This requires more preparation as the part need to be dissected and polished.

Table 2 - Mechanical properties		
Properties	**Subclause/table**	**Test reference**
Core hardness	4.3	5.1
Case hardness	4.3	5.2
Case depth	4.4 and Table 4	5.3
Torsional strenght	4.5 and Table 3	5.4
Ductility	4.6	5.5
Driveability	4.7 and Table 3	5.6
Embrittlement	4.8	5.7
Core hardness after retempering	4.9	5.8
Tensile breaking load	4.10 and Table 3	5.9



Plain or Flat Washers

The simple washers require hardness control as well, in particular for use with high tensile bolts. This is under ISO 7089 standard. It is imperative that compatible washers are used with various strength bolts. The loss of preload from "soft" washers can lead to catastrophic results. And, it is not quality related but by design.

Table 3 - Specifications and International Standards of reference

Material [a]	---	**Steel**		**Stainless steel**
	Grade [b]	---		A2 A4 F1 C1 C4
	International Standard	---		ISO 3506-1
Mechanical properties	Hardness class	200 HV	300 HV [c]	200 HV
	Hardness range [d]	200 HV to 300 HV	300 HV to 370 HV	200 HV to 300 HV
Tolerances	Product grade	A		
	International Standard	ISO 4759-3		

Set screws

The function of this hardware is designed primarily to bite into another part. Thus compressive force is experienced by the set screw during use. To meet the application requirement it is necessary for the set screw to be hard, at least at the tip. It has been observed that nuts are used to compliment the application. However, this is not the correct use of this fastener. The set screw is not designed for tensile load. At times this assembly use will break the set screw and it is not due to product quality but improper application.

As an appreciation to this fastener design, one of the other tests apart from hardness is the recess integrity, ISO 898 – 5. The set screw under test is placed into a threaded hole with the internal recess totally embedded. The test piece is then torqued to the appropriate torque. The recess is then checked for any fracture.

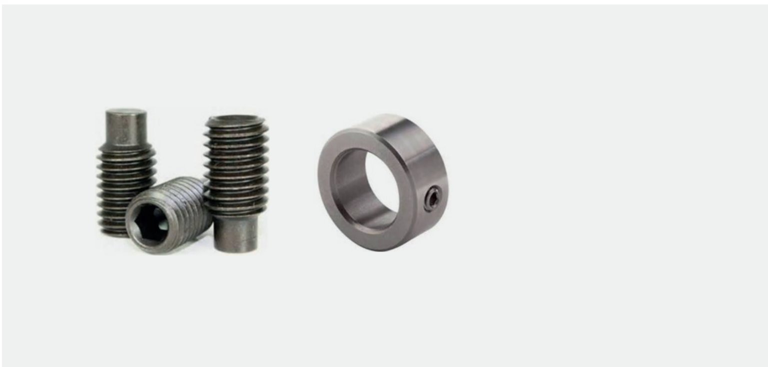


Table 1 - Designations of property classes in relation to Vickers hardness

Property class	**14H**	**22H**	**33H**	**45H**
Vickers hardness, HV min.	140	220	330	450

The important note of this test is that the recess portion is fully embedded into the threaded recess. This application test as part of the manufacturing control simulates the product application. For designers who plan to use this product, it is imperative that this is known and product is used appropriately.

The writer has experienced many feedbacks that the set screws used are "defective". Often, the parts are fine but application is not. It would be good if this product application is reviewed and its designed use is properly applied.

The set screw with appropriate washer and nut is a good initial design (new product) substitute for a standard bolt where the length of bolt is not determined or not possible. However, do not forget to replace the set screw assembly after the bolt assembly length is finalized.

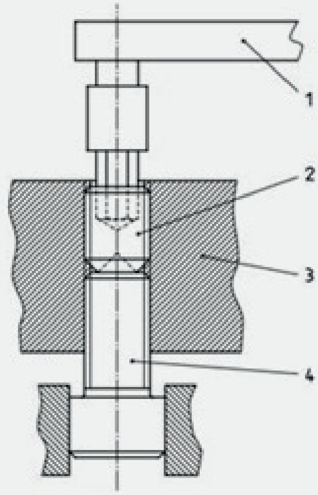


Table 3 - Mechanical properties

Mechanical properties			Property class [1]			
			14H	22H	33H	45H
Vickers hardness HV 10	---	min.	140	220	330	450
		max.	290	300	440	560
Brinell hardness HB, F = 30 D^2	---	min.	133	209	314	428
		max.	276	285	418	532
Rockwell hardness	HRB	min.	75	95	---	---
		max.	105	[2]	---	---
	HRC	min.	---	[2]	33	45
		max.	---	30	44	53
Torque strength	---	---	---	---	---	see table 5
Minimum height of non-decarburized thread zone, E	---	---	---	$^{1}/_{2}H_{1}$	$^{2}/_{3}H_{1}$	$^{3}/_{4}H_{1}$
Maximum depth of complete decarburization, G	---	mm	---	0,015	0,015	[3]
Surface hardness HV 0.3	---	max.	---	320	450	580

Summary

As it can be observed fastener hardware tests expectations are designed with relation to applications. This should not be a surprise. The important aspect is the proper application of fasteners. All industrial standard products are designed and tested for a specific application. Knowing the right specific designed application of simple fasteners is paramount to the outcome of the product. As we often say in Bossard, it is not how low or high the price of fasteners but selecting the right fastener for the right application is the important decision.

The challenges of using hardness results are when expectations to use hardness results to estimate for example the tensile strength or impact strength. For the moment, this is possible only for very limited application where empirical results are available for limited material range. For manufacturers, it is possible to have such relativity but still, the necessary tests are expected according to the standards.

Contact Bossard or visit our website, our Engineering Team will be happy to work with you and provide the necessary information leading to wise decisions.

Conclusion

The use of hardness measuring technique has come a long way. This technique has been integrated into many processes as part of the controls in manufacturing.

For fasteners and hardware, hardness testing is the more economical test process during manufacturing. The test is directly at parts, non-destructive and relatively straight forward. Overall process management, it is more convenient compared to tensile test.

However, hardness test alone does not totally fulfil the test requirements of fasteners and hardware. It needs to be complimented with other tests or application related tests.

Industrial Standards on Hardness Testing	
EN ISO 6506-1	Metallic materials – Brinell hardness test – Part 1: Test method
EN ISO 6506-2	Metallic materials – Brinell hardness test – Part 2: Verification and calibration of Brinell hardness testing machines
EN ISO 6506-3	Metallic materials – Brinell hardness test – Part 3: Calibration of reference blocks
EN ISO 6506-4	Metallic materials – Brinell hardness test – Part 4: Table of hardness values
ASTM E 10	Standard test method for Brinell hardness of metallic materials
EN ISO 6507-1	Metallic materials – Vickers hardness test – Part 1: Test Method
EN ISO 6507-2	Metallic materials – Vickers hardness test – Part 2: Verification of testing machines
EN ISO 6507-3	Metallic materials – Vickers hardness test – Part 3: Calibration of reference blocks
EN ISO 6507-4	Metallic materials – Vickers hardness test – Part 4: Tables and hardness values
ASTM E 384	Standard Test Method for Knoop and Vickers Hardness of Materials
EN ISO 6508-1	Metallic materials – Rockwell hardness test – Part 1: Test Method (scales A, B, C, D, E, F, G, H, K, N, T)
EN ISO 6508-2	Metallic materials – Rockwell hardness test – Part 2: Verification and calibration of testing machines (scales A, B, C, D, E, F, G, H, K, N, T)
EN ISO 6508-3	Metallic materials – Rockwell hardness test – Part 3: Calibration of reference blocks (scales A, B, C, D, E, F, G, H, K, N, T)
EN ISO 6507-4	Metallic materials – Vickers hardness test – Part 4: Tables and hardness values
ASTM E 18	Standard Test Method for Rockwell Hardness of metallic Materials
ISO/TR 10108	Steel – Conversion of hardness values to tensile strength values
ISO 18265	Metallic materials – Conversion of hardness values
ISO 14577-1	Metallic materials – Instrumented indentation test for hardness and materials parameters – Part 1 Test method
ISO 14577-2	Metallic materials – Instrumented indentation test for hardness and materials parameters – Part 2 Verification and calibration of testing machines
ISO 14577-3	Metallic materials – Instrumented indentation test for hardness and materials parameters – Part 3 Calibration of reference blocks
ASTM E 140	Standard hardness conversion tables for metals relationship among Brinell hardness, Vickers hardness, Rockwell hardness, superficial hardness, Knoop hardness, Scleroscope hardness and Leeb hardness

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