Mechanical Properties Analysis of Metal Materials Based on Hardness Test

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Keywords: hardness, Rockwell, steel, aluminum alloy, properties

Abstract: The article introduces the testing principle of Rockwell hardness. By measuring the Rockwell hardness of different metal materials, the mechanical properties of the same metal are analyzed. The different carbon contents of the same metal lead to different hardness. The different metal processing methods also lead to the different hardness of the metal. Analyze the reasons by the experimental data, to provide an effective basis for production.

1. Mechanical properties of metal materials

The mechanical properties of metal refer to a series of mechanical properties of materials under the action of force, which reflect the ability of metal materials to resist deformation or destruction under the action of various external forces.

The mechanical properties of metal include: elasticity, stiffness, strength, plasticity, hardness, impact toughness, fracture toughness and fatigue strength, etc. They are extremely important index to measure the properties of materials

2. Hardness

The hardness of metal can be considered as the resistance of local surface of metal material to plastic deformation under the action of contact pressure. Hardness is an important performance index to measure the hardness of metal materials. It can be understood as the material's resistance to elastic deformation, plastic deformation or damage, and it can also be expressed as the material's resistance to residual deformation and anti-damage. Hardness is not a simple physical concept, but a comprehensive index of mechanical properties such as elasticity, plasticity, strength and toughness.

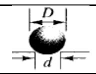
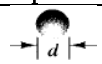
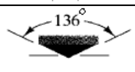
The tensile strength of most metal materials can be estimated from the hardness value. Therefore, the hardness value of materials is mostly specified in the technical conditions of design drawings. Hardness is sometimes required to check the quality of materials or processes. So, hardness test is widely used in production.

There are many test methods, according to the different test methods, they can be divided into static pressure method (such as Brinell hardness, Rockwell hardness, Vickers hardness), scratch method (such as Mohs hardness), rebound method (such as Shore hardness) and micro hardness, high temperature hardness and other methods. The most widely used method is compression. A hard head is used to press the surface of the sample at a certain pressure, causing an indentation in the metal, and the hardness value is determined according to the size of the indentation. The larger the indentation, the softer the material, on the contrary, the harder the material.

According to different types of hardness test methods such as indenter type and geometric size, it can be divided into three methods: Brinell method, Rockwell method and Vickers method.

The size, shape and loading mechanism of the indenter are shown in Table 1.

Table 1 Common types of hardness test indenter geometrie

Test		Indenter	Shape of Indentation		Load	Formula for hardness number
			Side view	Top view		
Brinell		10mm sphere of steel or tungsten carbide			P	BHN= $\frac{2P}{\pi D\left[D-\sqrt{D^2-d^2}\right]}$
Vickers		Diamond pyramid			P	VHN=1.72P/d12
Rockwell	ACD	Diamond cone			60kg 150kg 100kg	100-500t
	B FG	1/16 in. diameter steel sphere			100kg 60kg 150kg	130-500t
	EH	1/8 in. diameter steel sphere			100kg 60kg	

3. The Rockwell Hardness Tester

In this paper, Rockwell hardness test is selected for the experiment. Rockwell hardness test method is simple and rapid, and can measure the softest to hardest materials. Due to small indentation, it can measure the hardness of finished products and thinner parts. But also because of the small indentation, the test results of uneven tissue and hardness of materials are not accurate. Normally, three points should be measured from different positions of the specimen, and then its average value should be taken.

The Rockwell tester measures hardness by determining the depth of the indentation into the specimen under certain fixed conditions of test. The indenter can be either a steel ball or a diamond sphero-conical indenter. A minor load of 10 kg is first applied for the initial penetration, the instrument is zeroed and then the major load is applied corresponding to the standard Rockwell scale, for the specified time interval. The load is then reduced to the minor value and the depth of indentation is measured and converted to a hardness number on the readout device.

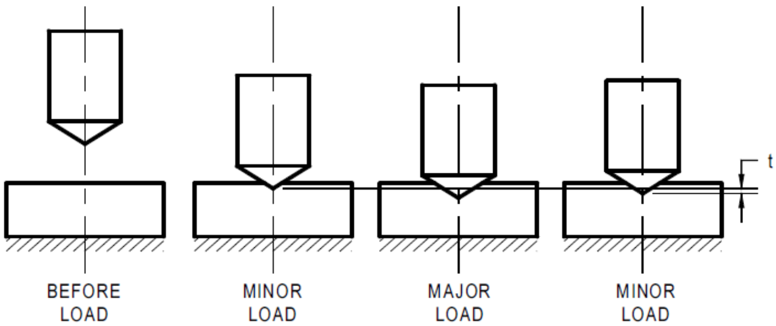


Figure 1 Sequence for Rockwell indentation

The range of adaptation of different Rockwell hardness scales. Each Rockwell hardness scale has a usable range, which is easily determined from the index on the durometer dial.

The Rockwell hardness test requires a sample, the thickness of which cannot be less than 10 times the depth of the residual indentation, and no obvious deformation marks can appear on the back side of the sample. The thickness of the sample determines the choice of load, The deformation caused by the load is less than the minimum thickness of the sample. For each hardness test, there is a minimum measurable thickness.

The scales of Rockwell hardness testers and surface Rockwell hardness testers are usually selected according to three factors: material type, sample thickness and hardness range. See Table 2 for the specific selection method.

Table 2 Different range of Rockwell hardness scales

Rock well scale	Hardness symbol	Application	Indenter	range
A	HRA	Sheet steel,Tungsten carbide,Very hard material,thin, hard and sheet materials	Diamond cone	20-88HRA
B	HRB	Medium hardness material,Such as annealing medium carbon steel	1/16in steel ball (1.5875 mm dia.)	20-100HRB
C	HRC	Hard steels、deep case-hardened	Diamond cone	20-70HRC
D	HRD	Thin hard steel; med. case-hardened	Diamond cone	40-77HRD
E	HRE	Very soft material,Such as Cast iron; Al; Mg; and bearing metals	1/8in steel ball (3.175 mm dia.)	70-100HRE
F	HRF	Annealed Cu alloys; thin soft sheets	1/16insteel ball (1.5875 mm dia.)	60-100HRF
G	HRG	Malleable CI; bronzes; Cu-Ni alloys	1/16in steel ball (1.5875 mm dia.)	30-94HRG
H	HRH	Soft materials; high ferritic; Al; Pb; Zn	1 /8insteel ball (3.175 mm dia.)	80-100HRH
K	HRK	Al and Mg alloys	ball 3.175 mm dia.	40-100HRK

4. Test Results

The test materials: 45, 65 annealed steel, aluminum alloy of different processes. Tested by Rockwell hardness tester, the test results are shown in Table 3.

Table 3 Hardness Values

material	process	scale	1	2	3	average value
45	annealed	HRA	54.6	54.6	54.1	54.4
65	annealed	HRA	54.6	54.8	55.2	54.9
Aluminum alloy	Cast state	HRH	67.1	60.3	72.2	66.5
	Solid solution treatment	HRH	95.5	96.1	95.9	95.8
	Rolling	HRH	105.1	104.0	104.5	104.5
	Aging treatment	HRH	110.4	112.1	111.5	111.3

5. Summary

(1) The hardness of a material is related to its composition and heat treatment process. Under the same heat treatment process, the higher the carbon content of the material, the higher the hardness of the material. For example, in annealed steel, 65 steel has higher carbon content than 45 steel, so it has higher hardness.

(2) The materials with the same composition have different final hardness depending on the heat treatment process used. For example, aluminum alloys have different process methods and their final hardness is also different.

The hardness of the alloy after solid solution treatment is higher than that of the cast state sample. The reason is that the solution treatment produces a solid solution strengthening effect.

The hardness in the rolled state is higher than the hardness in the unrolled.

This is caused by work hardening. Rolling causes plastic deformation of the metal, causes internal pinning, increases dislocation density, and has large interaction between dislocations, hindering mutual movement of dislocations.Therefore, the strength and hardness increase.

The hardness of aging state is higher than rolling state without aging treatment. In the aging treatment process, Cu and $CuAl_2$ with increasing hardness will be precipitated, resulting in gap solid solution strengthening.

(3) It has been proved that the hardness value and strength value of metal materials have an approximate and corresponding relationship. Because the hardness value is determined by the initial plastic deformation resistance and the continuing plastic deformation resistance, the higher the strength of the material, the higher the plastic deformation resistance, the higher the hardness value.

Acknowledgements

Supported by the professional innovation team construction project of Beijing vocational colleges.

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