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SYSTEMATIC ERROR OF LOADCELL TYPE ROCKWELL HARDNESS TESTING MACHINE ON ROCKWELL SCALE R

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Abstract – The Rockwell hardness testing scale R can be test plastic. But dead weights and load cell type of hardness tester give different results. This research focused on study of the machine operation behavior. The experiment results showed that testing cycle of load cell type hardness testing machine cannot performed according to testing condition. It causes hardness value are softer than using dead weight type.

Keywords: Rockwell scale R, Dead weights type hardness machine, Load cell type hardness machine

1. INTRODUCTION

Recently, a commercial Rockwell hardness machine in the market can be separated into two type by force application technique i.e., dead weights type and load cell type. The deadweight type used weights to apply test forces while load cell type used load cell and electronic feedback control. Dead weight type is quite inexpensive besides, it does not complicate to manufacture which following standard methods such as ISO6508:2005 [1] and ASTM E18-14[2]. However, inconveniences on using deadweight type is machine size that larger when it is design more various test forces used. As well, control of testing cycle could not precise due to oil damper property or disk cam mechanism. For these reasons the load cell type machine was introduced. The close-loop system with force transducer has been equipped in hardness machine. Size of hardness machine is independence from various selected test force and it quite small when compare with dead weight type.

On principle, Force can apply using screw press pass through indenter. Force signal given by load cell uses for force control either full close-loop or semi close loop feedback control. Thus it can operate many test force with precise testing cycle. Commonly, it claims to be realised with ISO6508:2005 and ASTM E18-14.

Rockwell hardness measurement on metallic materials has been widely used and studied [3] for a decade, because it is easy to use and comparable with other material properties such as tensile property. Mention on plastic materials, hardness measurement was not much studied compare with metallic materials. However, most of the testing method for plastic hardness measurement is quite similar with metal hardness test [4]. The testing cycle of plastic hardness test must be controlled precisely, due to material creep.

Fig. 1. Five hardness testing machines used in this research with two dead weights type and three load cell type hardness machine.

Table 1. Details of hardness machine used

Machine	Manufacturer name	Model No.	Serial No.
DW1	Mitutoyo corp.	ATK-F1000	291028
DW2	Akashi corp.	SHT-31	310039
LC1	Emco test	M4R 075 G3R	9440309
LC2	Mitutoyo corp.	HR-522	100080812
LC3	Wilson wolpert	660RLD/R	R10/R-101

In this paper the experimental section introduces an experiment on operation pattern of force, depth, testing cycle and hardness measurement of five hardness machine i.e., two dead weights type and three load cell type machine. Plastic test pieces and hardness blocks have been used to investigate the source of problem. Then in discussion section presents significant error from experiment results on load cell type machine compare with dead weights type. Most of error and root cause of problem came from unusual testing cycle which is the main objective of this research.

2. EXPERIMENT

In this section, force, depth, time and hardness measurement investigation pattern has present. Five hardness testers consist of three load cell type machine and two dead weights type machine have been used. The details of machines are described in Table 1 and the machines picture as shown in Fig. 1. To ensure that these hardness machines conformed to ISO 6508 and ASTM E18, the direct and indirect verification (force, depth, testing cycle and hardness value) were done before the experiment process beginning. The certified reference hardness blocks 35 HRA, 85HRA and 120 HRR were used as standard for direct verification.

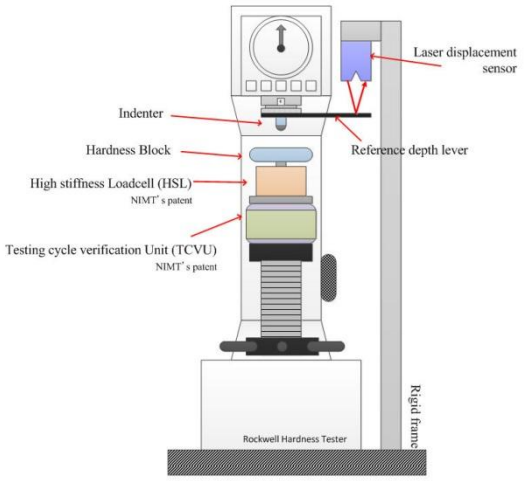

Fig. 2. The schematic of the experimental setup for investigation of force, depth, time and hardness measurement of hardness machine.

Fig. 3. DW1 equipped with HSL, TCVU and Laser displacement sensor.

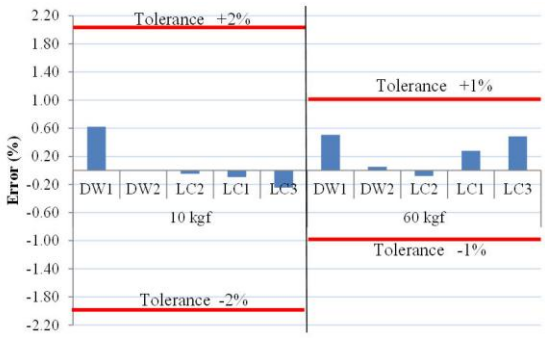

Fig. 4. Force verification results.

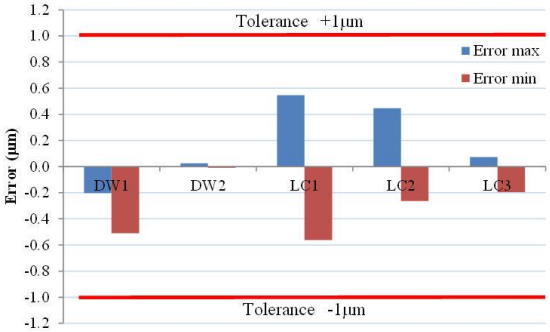

Fig. 5. Depth verification results.

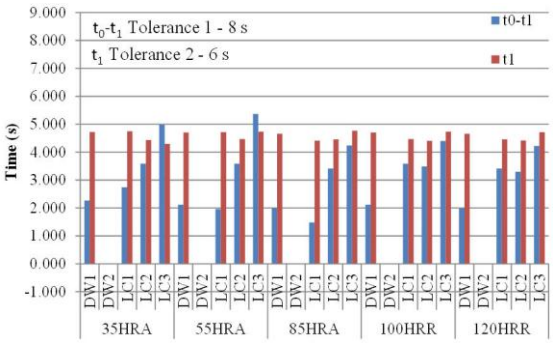

Fig. 6. Testing cycle verification results.

Fig. 7. Indirect verification results.

In the experimental setup, the behaviour of force, depth and time were investigated during machine operation by using High stiffness load cell (HSL) for force investigation, the testing cycle verification unit (TCVU, NIMT's patent) for time investigation and laser displacement sensor for depth behaviour investigation. Hardness machines were equipped with such equipment as shown in the schematic of the experimental setup, Fig. 2.

The HSL can measure test force during machine operation. It deforms less than 10 µm under 60 kgf of application force. This load cell deformation is obviously less effect to hardness measurement. Other equipment is TCVU, it can observe test force behaviour in function of time, which represents testing cycle of the measurement in real time based. The last one is laser displacement sensor that observed the movement of indenter pass through reference lever. It presents indentation depth of hardness measurement. The experiment setup with hardness machine is shown in Fig. 3.

The set of plastic test pieces composed of hardness level following, 85 HRR, 60 HRR and 50HRR then were tested according to ISO 2039-2:1987 [5] (that is equal to ASTM D785 [6]). The deviation of hardness measurement between set of test pieces were discussed in next section.

3. RESULTS AND DISCUSSION

3.1. Verification results

As long as Rockwell scale A and scale R using same total testing force i.e., 60kgf, thus they suit for checking the performance of hardness machine by way of comparing direct verification each other. The direct and indirect verification results are shown in Fig. 4-7.

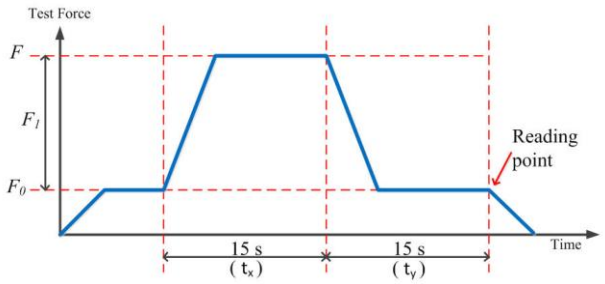

Fig. 8. Testing cycle diagram of ASTM D785 and ISO 2039

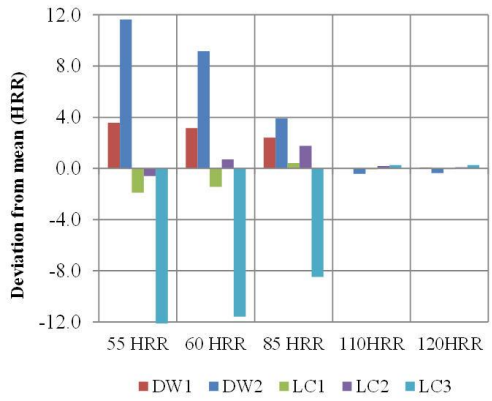

Fig. 9. Plastic hardness measurement according to ISO 2039.

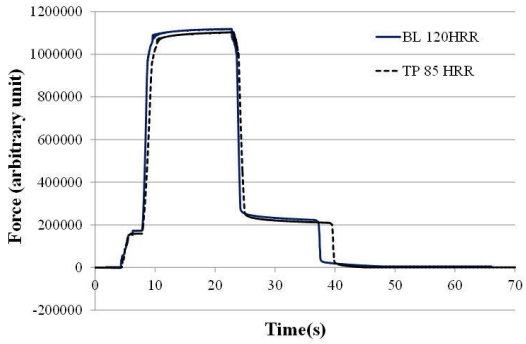

Fig. 10. Testing cycle in hardness scale HRR (plastic and metallic) of dead weights type machine. Measured by TCVU

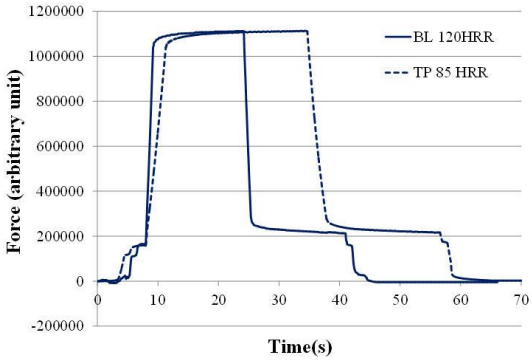

Fig. 11. Testing cycle in hardness scale HRR (plastic and metallic) of load cell type machine. Measured by TCVU

Verification results on HRR of five machines conformed to ISO6508 and ASTM E18 standards, nevertheless testing cycle definition in ISO 6508, ASTM E18 and ISO 2039-2 as well ASTM D 785 are different. These verification results present that all machine could be used for plastic hardness measurement (HRR scale)

3.2. Hardness measurement of plastic test pieces

Set of plastic test pieces at nominal value 85 HRR, 60 HRR and 55 HRR were measured using verified hardness machine. According to standard method for plastic hardness measurement (ISO 2039-2 and ASTM D 785) the crucial point is testing cycle. At the reference position after apply the minor load (10kfg) within 10 seconds then apply major load (150 kgf) for 15 seconds. After that record the hardness value at 15 seconds after remove major load. The testing cycle is shown in Fig. 8.

The experiment results in Fig. 9. obviously showed that load cell type machine get lower hardness value than dead weights type machine. This is conflict with indirect verification results in section 3.1. It is clearly that even though the machine conform to tolerance of ISO 6508, ASTM E14 or ISO 2039-2, it cannot guaranty the measurement results will be satisfactory especially in range 50-115 HRR for ISO 2309-2 and lower than 100 HRR for ASTM D 7850. In market, HRR block is available only in higher range (over 100 HRR), which is harder than plastic operation range. This experiment results confirmed that indirect verification with reference block harder than 100 HRR is not sufficient for plastic test.

3.3. Testing cycle verification for HRR measurement

Mention on hardness error described before, the first suspect is testing cycle operation cause to hardness error on plastic tests. In Fig. 10. express testing cycle pattern of dead weights type operation. It seemed to be typical. On the other hand, Fig.11. showed unusual of load cell type operation. There were longer time of t_x and t_y more than 10 seconds from setup condition.

Principally, testing cycle configurations of commercial type support only ISO 6508 and ASTM E 18 but they are not available for ISO 2039-2 and ASTM D 785. However, the experiment results on plastic material test proved testing cycle operation of load cell type could not conform to ISO 6508 and ASTM E 18. Time error was so large especially additional force application time (t_{TA}) as shown in table 2.

Table 2. Testing cycle verification results in HRR scale (plastic and metallic material)

Machine	Hardness block (120 HRR)			Plastic test pieces (85 HRR)		
	ISO 6508 and ASTM E 18		ISO 2309-2 and ASTM D 785	ISO 6508 and ASTM E 18		ISO 2309-2 and ASTM D 785
	t_0-t_1 (setup 4s)	t_1 (setup 4s)	t_x (setup 15s)	t_0-t_1 (setup 4s)	t_1 (setup 4s)	t_x (setup 15s)
DW1	1.787	6.105	15.087	2.148	6.472	15.617
DW2	1.218	3.963	15.000	3.056	3.987	15.000
LC1	1.207	5.678	14.963	3.535	23.27	26.480
LC2	4.014	3.884	14.908	3.770	15.39	23.851
LC3	2.903	6.184	15.530	3.015	20.316	75.974

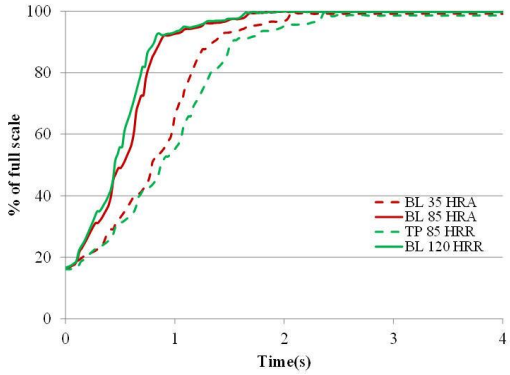

Fig. 12. Force increasing rate of DW1

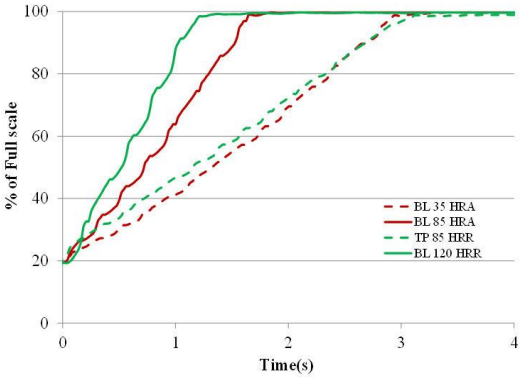

Fig. 13. Force increasing rate of LC1

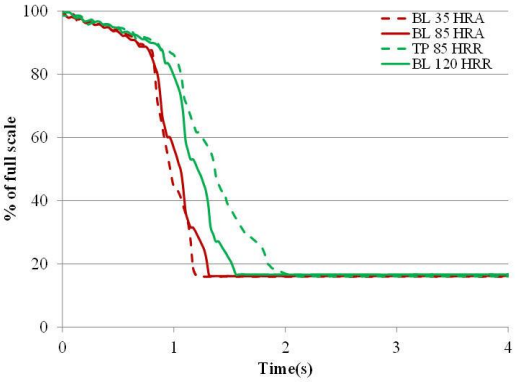

Fig. 14. Force decreasing rate of DW1

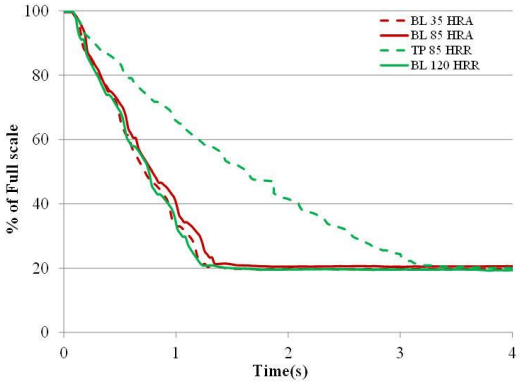

Fig. 15. Force decreasing rate of LC1

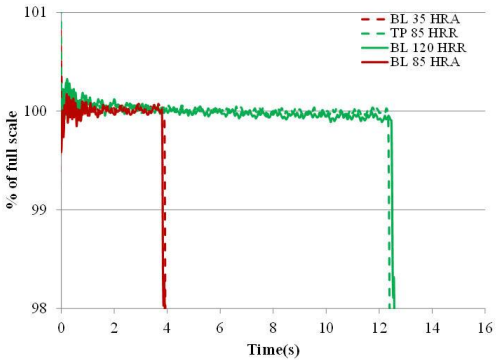

Fig. 16. DW1 force behaviour at 99% to 100% of total test force.

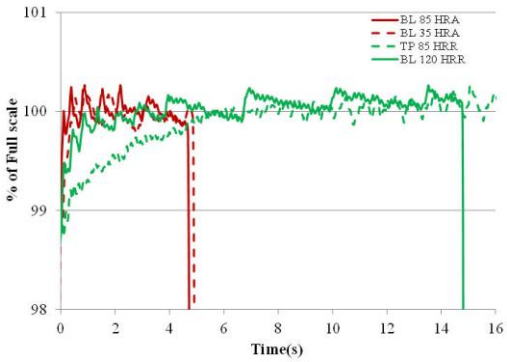

Fig. 17. DW1 force behaviour at 99% to 100% of total test force.

3.4. Force verification for HRR measurement

Mention on total test force application in Fig. 12-15, force rates relate to hardness level as shown in table 3. Considering additional force application time (t_{TA}), test time on plastic (softer than 100 HRR) takes longer than test time on metallic hardness block (harder than 100 HRR).

For load cell type, application time takes longer when compared with dead weights type as descried above. As reason, force rate are lower than another one.

Focusing at force from 99% up to 100% of total test force, it need more than 5 seconds as shown in Fig. 16-17. On the other hand, dead weights type does not need more time to reaching total test force. Removal of total test force time of load cell type similarly need more 2 seconds for 99% to 100% of removal total test force.

It could said that testing cycle of load cell type's operation exceed standard requirements. It is affected from inappropriate feedback control parameters as well as lower force rate application on plastic test.

Table 3. Force rate at the beginning of additional force applied (increasing rate) and starting removal of additional force (decreasing rate). Measured by HSL

Machine	Increasing rate (% of full scale / s)				Decreasing rate (% of full scale / s)			
	35HRA	85HRA	120HRR	85HRR	35HRA	85HRA	120HRR	85HRR
DW1	69.40	93.83	109	60.40	-182	-131	-108	-78.7
DW2	18.16	51.76	59.41	35.18	-245.3	-223.9	-306.5	-67.8
LC1	26.97	50.34	67.39	25.89	-64.66	-65.66	-66.03	-24.4
LC2	29.06	27.41	29.72	26.78	-105.3	-108.2	-105.3	-87.1
LC3	52.63	68.20	72.23	33.14	-81.50	-78.6	-83.03	-63.4

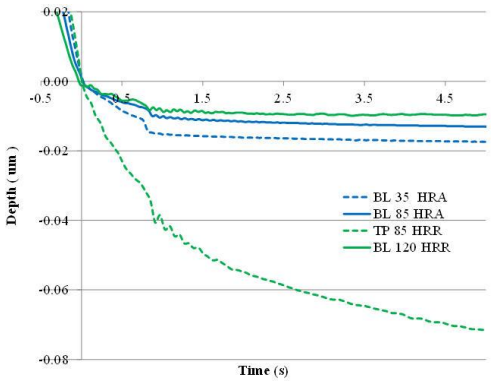

Fig. 18. Creep rate under total test force, *F at* t_1

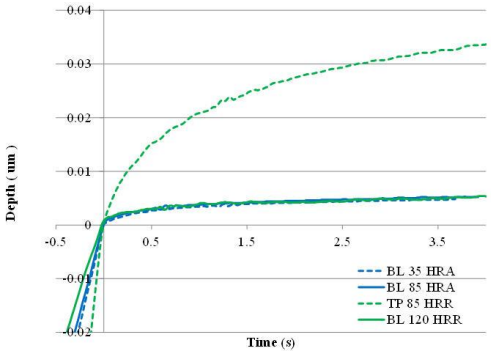

Fig. 19. Creep rate under preliminary test force after removed total test force, F_0 *at* t_R

Hardness Value	Creep rate (µm / s)		Hardness rate (HR / s)	
	F at t_1	F_0 at t_r	*F* at t_1	F_0 at t_r
35HRA	2.11	1.15	-1.05	-0.57
85HRA	4.69	1.84	-2.35	-0.92
85HRR	13.27	12.80	-6.64	-6.40
120HRR	2.20	1.0	-1.10	-0.50

Table 4. Creep rate at the beginning of additional force applied (increasing rate) and starting removal of additional force (decreasing rate). Measured by HSL

3.5. Creep characteristic on HRR measurement

Unusual longer testing time (t_x, t_y) result deeper penetration depth. Figure 18 and 19 showed creep behaviour under total test force and preliminary test force after removed total test force respectively. Creep rate specified for each material indicated in table 4. They are independent on type of hardness machine. However creep behaviour as described and longer time operation of load cell type could produce softer hardness results that are compliance with previous topic (3.1.)

4. CONCLUSIONS

Hardness testing machine that passed the verification requirements of ISO 6508-2 or ASTM E18-14 might not be able to test on plastic with Rockwell scale R according to ISO 2039-1 or ASTM D 785-03, especially load cell type hardness machine. The experiment results have shown that the load cell type machine cannot control its testing cycle to conform the testing condition i.e., addition force application time (t_0-t_1) and recovery time (t_R) are unusual longer than actual setup time (direct effect to hardness value) for measurement range below 100HRR. Moreover, these unusual testing cycles produces indentation creep that is directly effect to testing cycle problem.

In the future, the testing cycle of load cell type machine will be predicted and compensated with appropriate time setting. Then load cell type can be conformed ISO 2039-2:1987 and its measurement results can be compared with dead weighs type.

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