ASEAN Journal on Science & Technology for Development
Vol 36, No 1, 2019, 23-27
DOI 10.29037/ajstd.525
RESEARCH

Rockwell Hardness Testing of Pure Nickel Collimators for BNCT Application

Erasmus Prakasita[1,*], Yohannes Sardjono[2], and Budi Setyahandana[1]

[1]Faculty of Science & Technology Sanata Dharma University Campus III Paingan, Maguwoharjo, Depok, Sleman, Yogyakarta 55281, Indonesia
[2]Center of Accelerator Science and Technology, National Nuclear Energy Agency, Yogyakarta 55281, Indonesia
[*]Corresponding author: erasmusprakas22@gmail.com

KEYWORDS
Brinell hardness testing
Centrifugal casting
Nickel
Rockwell hardness testing

ABSTRACT In this study, Rockwell and Brinell hardness testing was used to examine material hardness. These methods were chosen because they are easy to carry out, relatively inexpensive, and almost all sizes and shapes can be tested, in which nickel hardness before and after centrifugal casting are identified and compared. These tests enable the determination of the hardness numbers of nickel collimators using for boron neutron capture therapy. The samples were five nickel plates with a dimension of 4.5×4.5 cm and five collimators. The collimators were cylindrical and made using centrifugal casting. The basic principle of the hardness test was to apply loading on the object being tested. The Rockwell test was used to assess the material's hardness from the difference of indentation depth, while the Brinell test was used to determine the hardness from the diameter of indentation. From the results of this test, the hardness number of nickel before centrifugal casting is 168.53 BHN or 86.13 HRB, while the hardness number after centrifugal casting is 115.68 BHN or 64.84 HRB. It can therefore be concluded that centrifugal casting decreased nickel hardness.

1. INTRODUCTION

Cancer is a very dangerous disease that can lead to death in humans (Qin et al. 2018; Sarfati et al. 2018). It is caused by multiple abnormal mutations of genes that lead to a genetic disorder (Hassanpour and Dehghani 2017). Many medical treatments are used to fight cancer, such as surgery, radioteraphy, chemoteraphy, hormonal therapy, radiation therapy, and immunotherapy (Sudhakar 2009; Lage and Romero 2018).

In Indonesia, a traditional herbal medicine known as *jamu* is one example of a traditional method of combating cancer. *Jamu* is made using plants from the Zingiberaceae family, such as *Curcuma*, which is used to treat many ailments. Notably, *Curcuma longa* contains curcumin, which has the potential to prevent and treat cancer (Elfahmi et al. 2014).

Apart from medical care, there is another form of treatment called boron neutron capture therapy (BNCT). BNCT is a cancer treatment method that uses boron and neutron radiation. Boron is delivered to the cancer cells of the patients followed by thermal neutron radiation. When the neutron beam is captured by boron, it undergoes a nuclear reaction (Romero-Canelón et al. 2015; Kasesaz et al. 2016; Maitz et al. 2017). The reaction can be written as shown in Equation 1:

$$^{10}B + n \rightarrow {}^{7}Li + {}^{4}He \tag{1}$$

^{10}B captures the neutron and forms ^{11}B. The nuclear reaction releases an alpha particle and a lithium nucleus (Nedunchezhian et al. 2016). These particles have a linear energy transfer of 196 keV/m and 162 keV/m, respectively, with track lengths around one cell in diameter. The cancer cells will absorb more boron than the healthy cells, due to their accelerated metabolism. Boron is used because it has a high cross section and is not toxic (Brandao and Campos 2009). One of BNCT's advantages is that this method has less of an effect on healthy cells (Bilalodin et al. 2017).

For the purposes of BNCT, the cancer cells need to be irradiated using thermal neutrons, but the neutron beam from the neutron source is mixed, containing fast neutrons, epithermal neutrons, and thermal neutrons (Kondo et al. 2016). These fast neutrons should be moderated into epithermal neutrons using a BNCT collimator (Zhu et al. 2018). Subsequently, the epithermal neutrons will be moderated again into thermal neutrons when going through the patient's skin (Fantidis and Nicolaou 2018). Based on the International Atomic Energy Agency's criteria, the minimum epithermal flux for BNCT is 10^9 epithermal neutrons cm^{-2} s^{-1} (International Atomic Energy Agency 2001). BNCT collimators consist of a reflector, moderator, collimator, shielding, and filter (Hassanein et al. 2018; Bavarnegin et al. 2017).

Mujiyono et al. (2018) manufactured a BNCT collimator from nickel using centrifugal casting. Casting is a manufacturing method to produce a metal material, and centrifugal casting is a casting method that uses centrifugal force from the rotating mould (Iqbal et al. 2014; Ebhota et al. 2016).

Hardness is the resistance of a material to mechanical deformation (Aydemir et al. 2011). In this research, the collimator was tested for its hardness using Rockwell hardness testing and Brinell hardness testing. Rockwell hard-

TABLE 1. The scale of Rockwell hardness with the appropriate indentor type, applied force, and application used.

Scale symbol	Indentor type	Preliminary force N (kgf)	Total Force N (kgf)	Typical applications
A	Spheroconical Diamond	98.07 (10)	588.4 (60)	Cemented carbides, thin steel, and shallow case hardened steel
B	Ball – 1,588 mm (1/16 in.)	98.07 (10)	980.7 (100)	Copper alloys, soft steels, alumunium alloys, malleable iron, etc.
C	Spheroconical Diamond	98.07 (10)	1471 (150)	Steels, hard cast irons, pearlitic malleable iron, titanium, deep case hardened steel, and other materials harder than HRB 100
D	Spheroconical Diamond	98.07 (10)	980.7 (100)	Thin steel and medium case hardened steel, and pearlitic malleable iron
E	Ball – 3,175 mm (1/8 in.)	98.07 (10)	980.7 (100)	Cast iron, alumunium and magnesium alloys, and bearing metals
F	Ball – 1,588 mm (1/16 in.)	98.07 (10)	588.4 (60)	Anncaled copper alloys, and thin soft sheet metals
G	Ball – 1,588 mm (1/16 in.)	98.07 (10)	1471 (150)	Malleable irons, copper-nikel-Zinc and cupro-nickel alloys
H	Ball – 3,175 mm (1/8 in.)	98.07 (10)	588.4 (60)	Alumunium, zinc, and lead
K	Ball – 3,175 mm (1/8 in.)	98.07 (10)	1471 (150)	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect
L	Ball – 6,350 mm (1/4 in.)	98.07 (10)	588.4 (60)	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect
M	Ball – 6,350 mm (1/4 in.)	98.07 (10)	980.7 (100)	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect
P	Ball – 6,350 mm (1/4 in.)	98.07 (10)	1471 (150)	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect
R	Ball – 12,70 mm (1/2 in.)	98.07 (10)	588.4 (60)	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect
S	Ball – 12,70 mm (1/2 in.)	98.07 (10)	980.7 (100)	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect
V	Ball – 12,70 mm (1/2 in.)	98.07 (10)	1471 (150)	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect

ness testing is an indentation hardness test (Low 2001), which is widely used for metal product testing (Song et al. 1998). ASTM International and the International Organization for Standardization defined over 30 Rockwell hardness scale. The properties of the material being tested determines which Rockwell hardness scale should be used (Low and Machado 2018). For a nickel material, a Rockwell hardness scale B is used. Table 1 shows the list of the Rockwell hardness scale.

The Rockwell hardness test is performed by applying a preliminary test force with an indentor to on the sample. The sample will be indented, and the depth of indentation is measured. Then, the indentor force is increased and applied to the sample. The final depth from the second indention is measured. The difference between the first and second indentation depths will determine the Rockwell hardness value (ASTM International 2017).

The Brinell hardness test, meanwhile, is performed by applying force with an indentor on the surface of sample. The force is applied in a specified time so the material will reach its final deformation. The Brinell hardness value will be calculated from the diameter of indentation in the surface of the object (Barajas et al. 2017; Gyurkó and Borosnyói 2015).

2. MATERIALS AND METHODS

2.1 Samples/objects to be tested

The material tested in this study was a BNCT collimator and nickel (Ni) metal. Five collimators and five nickel metal pieces in total were tested. Specifically, the number of samples for each material used in the test were as follows: five nickel metal plates before becoming a collimator, and collimator numbers 3, 6, 8, 10, and 12. The dimensions of each collimator sample is shown in Table 2. The design of the collimators that were tested is shown in Figure 1.

The data taken in this study include test data from Rockwell and Brinell testing. Furthermore, data comparisons between pure nickel metal samples and nickel collimators were made to analyze the relationship between the data obtained.

2.2 Hardness testing of nickel plate

Hardness testing was carried out using two different hardness tests, namely Brinell and Rockwell tests. Brinell hardness testing took place under the following conditions: the scale of testing was BHN, the indentor type was 5 mm in diameter, and the pressure load was 750 kg.

The Brinell test was carried out three times on the samples and its randomly indented. The results of the nickel Brinell hardness test were later converted into Rockwell yield calculations. Brinell hardness testing is shown in Figure 2.

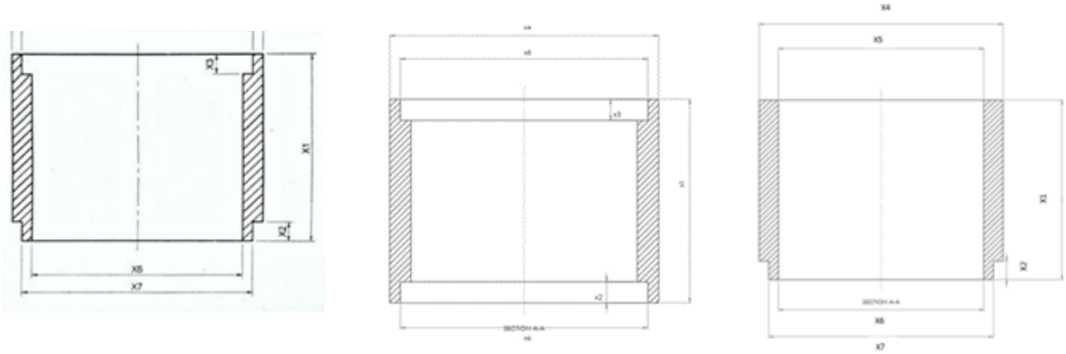
From the Brinell hardness test, the diameter of the indentation trace was 2.3 mm. From this result, we can determine the Brinell hardness value using Equation 2 (Awotunde et al. 2014).

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})} \tag{2}$$

where P is the force applied by the indentor (kg), D is the diameter of the indentor (mm), and d is the diameter of the indented sample (mm). Next, the Brinell hardness values were converted to Rockwell hardness scale B.

2.3 Hardness testing of collimators

The Rockwell hardness test was carried out on five nickel collimators, under the following conditions: the test scale was B (HRB), the indentor type was Ball, 1/16" diameter, and the load emphasis was 981 N.



(a) (b) (c)

FIGURE 1. Collimator design: (a) collimators number 3, 5, and 8; (b) collimator number 10; (c) collimator number 12.

TABLE 2. Size of collimator.

Collimator code	X1	X2	X3	X4	X5	X6	X7
	145	15	15	Ø190	M175x3	Ø160	M175x3
A (03)	139.7	10.7	6.2	178.66	168.16	156.46	171.06
B (06)	137	9.8	11.05	178	167.7	164.7	172
C (08)	144	10.4	15.6	178	166.2	159	169.8
D (10)	151	12.7	14.1	188	169	166.5	188
E (12)	105.7	13.2	-	173	158.2	158.2	162

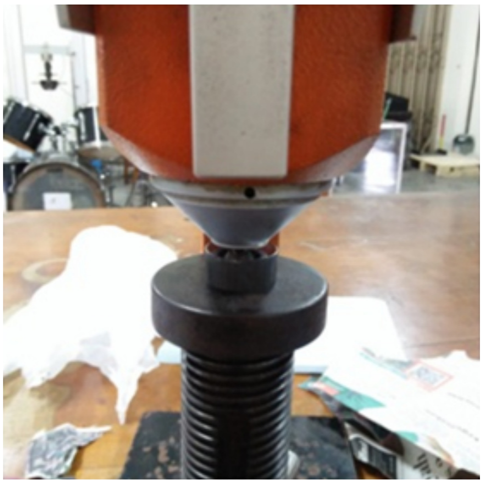


FIGURE 2. Brinell hardness test.

FIGURE 3. Rockwell hardness test with ball indentor.

In this study, the Rockwell hardness test was carried out five times on the nickel collimators and was randomly indented (Figure 3).

3. RESULTS AND DISCUSSION

Using Equation 2, the Brinell hardness number was obtained and listed as shown in Table 3.

Data from the Brinell test results on nickel metal showed the results of 168.53 BHN and were converted to Rockwell hardness numbers. The Rockwell hardness obtained showed the result of 86.13 HRB. The Rockwell hardness numbers for the collimators are shown in Table 4.

Collimator numbers 3, 6, 8, 10, and 12 are referred to as samples A, B, C, D, and E, respectively. The Data from the Rockwell hardness test on the nickel plates before the centrifugal casting process was 86.13 HRB and the mean results of the collimator hardness test after the centrifugal casting process on the Rockwell hardness test were 61.48 HRB. Thus, the centrifugal casting process affects the hardness of nickel collimators.

The data obtained from the Rockwell hardness testing on the nickel collimators showed that the average hardness decreased compared with the pure nickel metal. In collimators A, B, C, and E, the average hardness results showed a decrease compared with the pure nickel metal hardness. The highest value was only seen in collimator D, with an average number of 90.92 HRB.

The rolling process of nickel metal material used for collimators affects the hardness of the collimator, because during the rolling process, the nickel metal material will experience strain hardening on the metal material plate. During the centrifugal casting stage, the hardness of the collimator will decrease compared with the hardness of the nickel metal, because the hardness of nickel metal material returns evenly or as before.

The decrease in hardness can occur because the rotation of the centrifugal casting process is still considered to

TABLE 3. Nickel metal sample Brinell hardness test data.

No	Indentor trail (mm)	BHN	Conversion to Rockwell
1	2.3	168.53	86.13
2	2.3	168.53	86.13
3	2.3	168.53	86.13

TABLE 4. Data testing of nickel colimator hardness.

Sample	Average HRB	Conversion HB
A	54.54	100.81
B	64.84	115.68
C	52.16	98.16
D	90.92	188.6
E	44.92	89.92
Average	61.48	118.63

be less than the standard, which results in air being trapped in the collimator. In addition to the aforementioned factors, the decrease in density can also occur due to the cooling process when the centrifugal casting takes place quickly. Because the longer the rounds are carried out, the more material the resulting meeting will be, the more perfect the resulting hardness will be.

4. CONCLUSIONS

The results of this study showed that the centrifugal casting process carried out on nickel metal material causes a decrease in collimator hardness. The Brinell and Rockwell hardness tests showed values of 168.53 BHN and 86.13 HRB, respectively. Looking at specific collimators, the Brinell hardness test result of nickel collimator was 100.81 BHN, while the Rockwell hardness test result was 54.54 HRB. In collimator B, these values were 115.68 and 64.84 HRB, respectively. Collimator C was middling, with a Brinell hardness test result of 98.16 BHN and Rockwell hardness test result of 52.16 HRB. In collimator D, the Brinell hardness test result was 188.6 BHN, while the Rockwell hardness test result was 90.92 HRB. Finally, in collimator D, the Brinell hardness test result was 89.92 BHN and Rockwell hardness test result was 44.92 HRB. In collimator number 10, the highest values of the hardness tests were found, indicating that the collimator was adequate for usage in BNCT.

ACKNOWLEDGMENTS

The authors would like to thank Yohanes Sardjono as our lecturer in BATAN for his assistance and guidance. We are also grateful to our campus lecturer, Budi Setyahandana M.T., who unremittingly encouraged and helped us during the conducting of this research and writing of this manuscript.

REFERENCES

ASTM International. 2017. Standard test methods for rockwell hardness of metallic materials. Technical report. ASTM International. West Conshohocken.

Awotunde WO, Olatunde OB, Ponle EA, Fatukasi SO. 2014. Design, fabrication and performance evaluation of a hardness testing machine. IOSR J Eng. 4(5):1–6.

Aydemir B, Cal B, Salman S. 2011. The advantages of new generation hardness measurement methods. Turkey: Center for Quality, Faculty of Mechanical Engineering, University of Kragujevac. p. 337–344.

Barajas C, de Vicente J, Caja J, Maresca P, Gómez E. 2017. Considerations to the hardness Brinell measurement using optical equipment. Procedia Manuf. 13:550–557. doi:10.1016/j.promfg.2017.09.089.

Bavarnegin E, Kasesaz Y, Wagner FM. 2017. Neutron beams implemented at nuclear research reactors for BNCT. J Inst. 12(05):P05005. doi:10.1088/1748-0221/12/05/P05005.

Bilalodin B, Kusminarto K, Hermanto A, Sardjono Y, Sunardi S. 2017. Double layer collimator for BNCT neutron source based on 30 MeV cyclotron. Indones J Phys Nucl Appl. 2(3):124–127. doi:10.24246/ijpna.v2i3.124-127.

Brandao SF, Campos TPR. 2009. Dosimetric analysis of BNCT - Boron Neutron Capture Therapy - coupled to ^{252}Cf brachytherapy. 2009 International Nuclear Atlantic Conference. Rio de Janeiro: Associação Brasileira de Energia Nuclear.

Ebhota WS, Karun AS, Inambao FL. 2016. Centrifugal casting technique baseline knowledge, applications, and processing parameters: overview. Int J Mater Res. 107(10):960–969. doi:10.3139/146.111423.

Elfahmi, Woerdenbag HJ, Kayser O. 2014. Jamu: Indonesian traditional herbal medicine towards rational phytopharmacological use. J Herb Med. 4(2):51–73. doi:10.1016/j.hermed.2014.01.002.

Fantidis JG, Nicolaou G. 2018. Optimization of beam shaping assembly design for boron neutron capture therapy based on a transportable proton accelerator. Alexandria Eng J. 57(4):2333–2342. doi:10.1016/j.aej.2017.08.004.

Gyurkó Z, Borosnyói A. 2015. Brinell-hardness testing and discrete element modelling of hardened concrete. Epitoanyag - J Silic Based Compos Mater. 67(1):8–11. doi:10.14382/epitoanyag-jsbcm.2015.2.

Hassanein A, Hassan M, Mohamed NM, Abou Mandour M. 2018. An optimized epithermal BNCT beam design for research reactors. Prog Nucl Energy. 106:455–464. doi:10.1016/j.pnucene.2018.03.018.

Hassanpour SH, Dehghani M. 2017. Review of cancer from perspective of molecular. J Cancer Res Pract. 4(4):127–129. doi:10.1016/j.jcrpr.2017.07.001.

International Atomic Energy Agency. 2001. Current status of Neutron Capture Therapy. Technical publication 1223. International Atomic Energy Agency. Vienna.

Iqbal M, Patel S, Vidyarthee G. 2014. Simulation of casting and its validation by experiments. Int J Eng Sci Res Technol. 3(8):555–565.

Kasesaz Y, Bavarnegin E, Golshanian M, Khajeali A, Jarahi H, Mirvakili S, Khalafi H. 2016. BNCT project at Tehran Research Reactor: current and prospective plans. Prog Nucl Energy. 91:107–115. doi:10.1016/j.pnucene.2016.04.010.

Kondo N, Michiue H, Sakurai Y, Tanaka H, Nakagawa Y, Watanabe T, Narabayashi M, Kinashi Y, Suzuki M, Masunaga Si, Ono K. 2016. Detection of γH2AX foci in mouse normal brain and brain tumor after boron neutron capture therapy. Rep Pract Oncol Radiother. 21(2):108–112. doi:10.1016/j.rpor.2014.10.005.

Lage A, Romero T. 2018. Back and forth between cancer treatment and cancer control programs: Insights from the Cuban experience. Semin Oncol. 45(1-2):12–17. doi:10.1053/j.seminoncol.2018.04.004.

Low S, Machado RR. 2018. Technique to reduce bending issues in Rockwell B scale hardness reference blocks:

preliminary results. J Phys Conf Ser. 1065:062006. doi: 10.1088/1742-6596/1065/6/062006.
Low SR. 2001. Rockwell hardness measurement of metallic materials. Special Publication (NIST SP) - 960-5.
Maitz CA, Khan AA, Kueffer PJ, Brockman JD, Dixson J, Jalisatgi SS, Nigg DW, Everett TA, Hawthorne MF. 2017. Validation and comparison of the therapeutic efficacy of boron neutron capture therapy mediated by boron-rich liposomes in multiple murine tumor models. Trans Oncol. 10(4):686–692. doi:10.1016/j.tranon.2017.05.003.
Mujiyono M, Suharto S, Mukhammad AFH, Nurhadiyanto D, Sumowidagdo AL. 2018. Manufacture of nickel collimator for BNCT: smelting of nickel using electrical arc furnace and centrifugal casting preparation. Indones J Phys Nucl Appl. 3(1):21–28. doi:10.24246/ijpna.v3i1.21-28.
Nedunchezhian K, Aswath N, Thiruppathy M, Thirugnanamurthy S. 2016. Boron neutron capture therapy - a literature review. J Clin Diagn Res. 10(12):ZE01–ZE04. doi:10.7860/JCDR/2016/19890.9024.
Qin SY, Cheng YJ, Lei Q, Zhang AQ, Zhang XZ. 2018. Combinational strategy for high-performance cancer chemotherapy. Biomaterials. 171:178–197. doi:10.1016/j.biomaterials.2018.04.027.
Romero-Canelón I, Phoenix B, Pitto-Barry A, Tran J, Soldevila-Barreda JJ, Kirby N, Green S, Sadler PJ, Barry NP. 2015. Arene ruthenium dithiolato–carborane complexes for boron neutron capture therapy (BNCT). J Organomet Chem. 796:17–25. doi:10.1016/j.jorganchem.2015.05.011.
Sarfati D, Garvey G, Robson B, Moore S, Cunningham R, Withrow D, Griffiths K, Caron NR, Bray F. 2018. Measuring cancer in indigenous populations. Ann Epidemiol. 28(5):335–342. doi:10.1016/j.annepidem.2018.02.005.
Song JF, Low S, Pitchure D, Germak A, DeSogus S, Polzin T, Yang HQ, Ishida H. 1998. Establishing a worldwide unified Rockwell hardness scale using standard diamond indenters. Measurement. 24(4):197–205. doi:10.1016/S0263-2241(98)00052-9.
Sudhakar A. 2009. History of cancer, ancient and modern treatment methods. J Cancer Sci Ther. 01(02):i–iv. doi: 10.4172/1948-5956.100000e2.
Zhu X, Wang H, Lu Y, Wang Z, Zhu K, Zou Y, Guo Z. 2018. 2.5 MeV CW 4-vane RFQ accelerator design for BNCT applications. Nucl Instrum Methods Phys Res, Sect A. 883:57–74. doi:10.1016/j.nima.2017.11.042.