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Microstructural dependence of Barkhausen Noise in the Neutron Irradiated Reactor Pressure Vessel Steel

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Abstract

The effects of neutron irradiation on magnetic parameters were investigated in the reactor pressure vessel (RPV) steel having different microstructure partially due to the difference in the steel refining process. The samples were irradiated in a research reactor with a fluence of 4.5×10^{19}n/cm^2 at 288℃. The measurement of Barkhausen noise (BN) was conducted to explore the relationship between the microstructural state and domain wall motion. The BN profiles of unirradiated samples showed consistent change with microstructure (grain size, carbide morphology, lath width), but the neutron irradiated samples did not show a consistent change.

1. Introduction

The BN can be used as a useful tool for non-destructive evaluation, because of the sensitive characteristics on microstructure and residual stress. It has already been used to assess the quality of heat treatment, to measure the surface treatment depth [1]. However, for plain steels, no wide description and understanding of the microstructural features on magnetic BN is available. Even though several studies [2] have been made on microstructure characterization using BN. A clear understanding on the individual influence of different microstructural parameters such as grain size, and precipitation of second-phase particles on the generation of BN has still not been well established [3]. Recently, it has been expected to be a promising tool for monitoring the radiation damage non-destructively [4]. In this study BN characteristics were investigated on both unirradiated and irradiated RPV steels having different microstructure partially due to the difference in the steel refining processes. TEM on thin films and carbon replications were performed for microstructural investigation, and BN envelopes were measured for the magnetic properties investigation. Results of each evaluation on microstructure and magnetic properties were interpreted in terms of domain wall dynamics.

2. Experimental

The samples of four kinds of SA508-3 low alloy steels, which differ in steel refining process, were used in the investigation. The samples were irradiated in a research reactor with a fluence of 4.5×10^{19} n/cm^2 at 288℃, and the chemical compositions are shown in table 1.

Material	C	Si	Ni	Mn	Cr
A	0.18	0.08	0.77	1.40	0.15
B	0.17	0.10	0.82	1.35	0.16
C	0.21	0.24	0.92	1.36	0.21
D	0.19	0.20	0.82	1.44	0.15
Material	M	Cu	P	N	Al
A	0.53	0.06	0.005	0.004	<20ppm
B	0.50	0.03	0.006	55ppm	0.015
C	0.49	0.03	0.007	-	0.022
D	0.55	0.03	0.006	-	0.020

Table 1. Chemical composition of SA 508 - 3 low alloy steel A, B, C, and D.

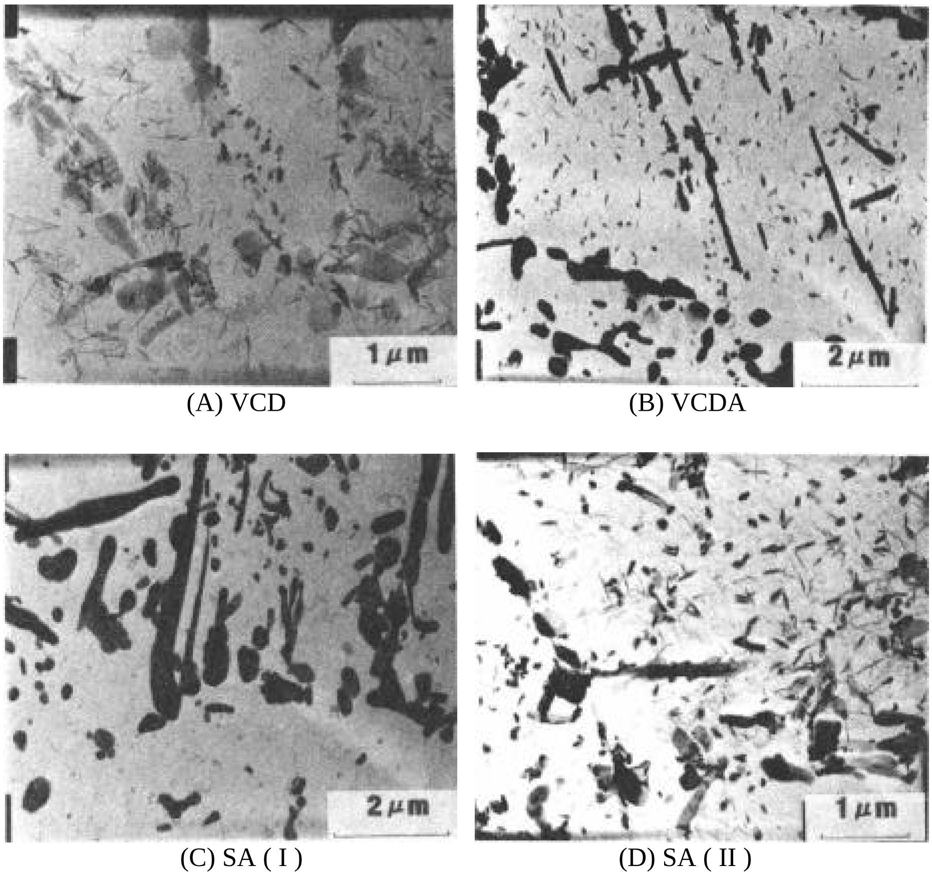
Microstructures and carbide morphologies, as well as size and numbers, were investigated by TEM (JEOL 2000FX) on thin films and carbon replicas. The samples were subjected to a continuously varying cyclic magnetic field with a frequency 50 mHz in an electromagnetic yoke. The BN envelope was obtained from the signal passed through the electronic circuit. The envelopes were acquired for half the magnetization cycle, that is from a negative maximum of the field to a positive maximum of the field.

3. Results and Discussion

The results of the microstructural investigation by optical microscope and TEM (thin film, carbon replica) are summarized in Table 2. Typical carbide morphologies, size, and distribution observed by TEM(thin film) are shown in Fig. 1. The four materials show largely the same tempered bainitic microstructure, but some differences in the size of grain and lath width, and in the size and distribution of carbides that were observed. The BN profiles of unirradiated samples are shown in Fig. 2 (a). The BN profiles of the sample A, B, and C characterized as a single peak near the coercive force. However, the BN profile in the sample D is characterized by a low amplitude and broad peak distribution : it occurs at broad field range.

material	Precipitates, Carbide, and Bainite Morphology and Lath width(㎛)
A	Round(dia: 0.5㎛), Fine Needle (50 100nm), agglomerated, large and localized coarse carbides, underdeveloped lath boundary, lath width: 5㎛, coarse interlath carbide PPts No:$6\times10^{7}/nm^{2}$ (Round:Needle=1:0.85)
B	Round(dia:0.05 0.25㎛), Fine Needle (80nm), Slightly agglomerated, Semi-underdeveloped lath boundary, lath width:5㎛, Interlath carbide, PPts No.:$8.5\times10^{6}/mm^{2}$ Round: Needle=1:22
C	Round(dia:0.025㎛, Needle(80nm), Square -like needle(100nm), Three types of carbides morphology, PPts at GB and matrix, Well developed lath boundary, lath width:3.5㎛, Interlath carbides, PPts No.:$3.1\times10^{9}/mm^{2}$, Round:Needle:Square Needle =1:1.75:0.46
D	Round(<0.05㎛), Needle(50 100nm), Fine round carbide, Well developed lath boundary, lath width : 2㎛, No interlath carbides, PPts No.:$6.7\times10^{7}/cm^{2}$, Round: Needle=1:0.39

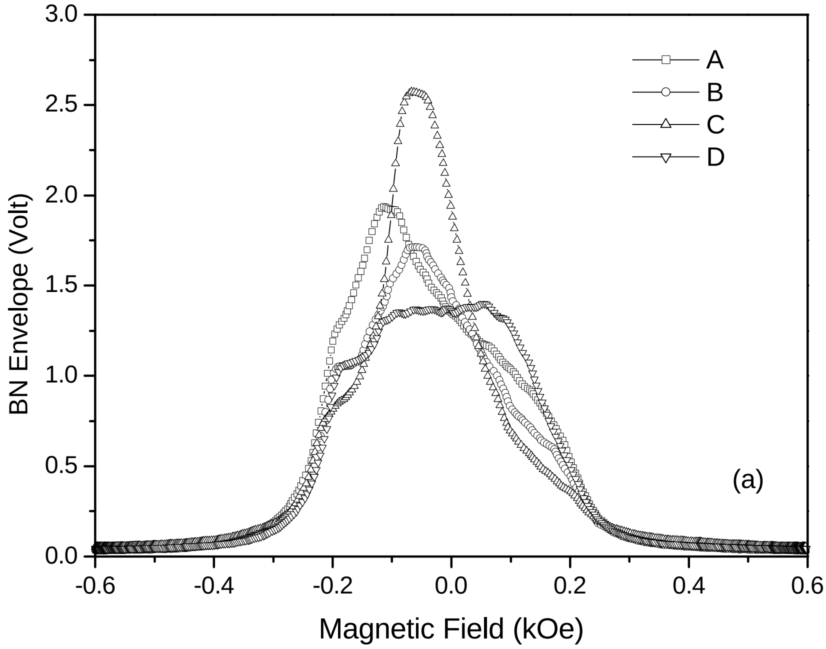
Table 2. Grain size, carbide and precipitates morphology, and bainite lath structure obtained by optical microscope, and TEM on thin films and carbon replicas for A, B, C, and D steels.



(A) VCD (B) VCDA

(C) SA (I) (D) SA (II)

Fig. 1 Transmission electron micrographs showing the microstructure of samples : A, B, C and D.



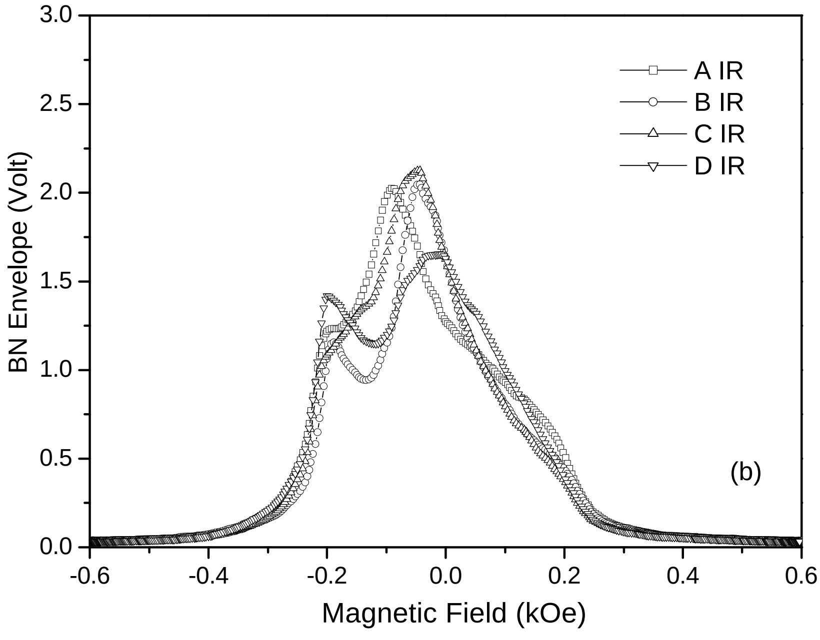


Fig. 2 The BN profiles of unirradiated (a) and irradiated (b) samples

The BN peak height depends on the number of domain walls moving at a given instant and the mean free path of the domain wall displacement. The BN peak height increases by increasing the mean free path of domain wall moving between pinning sites. Although the grain size of sample A is greater than that of sample C, the BN peak height is lower than that of sample C, which is the result of two opposite effects influencing the domain wall motion.

Sample A is characterized by a coarse grain and larger carbide (greater than 0.5 ㎛). It is known that the large size carbides reduce the mean free path for the movement of the reversal domain walls by making spike domain resulting in the decrease of BN height [5], but the large grain increases the height of BN by increasing the mean free path [6].

The morphology of the sample C with high BN pulse height is characterized by fine precipitates at grain boundary and matrix, and very high precipitates density. Fine precipitates within the matrix give rise to a much higher interaction with domain walls than interstitial atom or localized in the grain boundary. As the number of precipitates is increased, the magnetostatic energy related to the formation of magnetic poles is increased. The duration of elementary jumps is increased, the number of jumps are increased, therefore the amplitude of BN is increased [7]. The BN peak of sample B is low and wider than that of sample A and C. These difference are expected to be mainly due to the intergranular cementite precipitates, which act as strong pinning points for the domain wall in tempered martensite, leading to a nucleation of elementary events greater in tempered martensite. The broad and low peak of BN in sample D would be related with narrow lath width and no interlath carbide. The narrow lath width would reduce the mean free path of the domain wall displacement, resulting in a decrease of the BN height.

The irradiation response of four kinds of samples having different microstructure is shown in Fig. 2 (b). The behavior of BN after neutron irradiation did not show consistent change with microstructure. Other results of neutron irradiated RPV steel having various microstructure did not show consistent trends on magnetic properties with microstructure [8]. In the sample A, the BN profile before and after irradiation showed little change. In the sample C, the BN peak height measured on the irradiated sample was significantly below that of the unirradiated one. However, the BN peak height was increased by neutron irradiation in the sample B and D.

The most important microstructural change under neutron irradiation is the atomic displacement creating defect clusters, the size of which is known to be in the order of several nanometers [9]. The origin of the change of magnetic properties under irradiation is not established yet; however, the defects induced by irradiation seem to be primarily responsible for it [4]. Since irradiation induced defects interact with the microstructural parameter such as carbide and precipitate, it gives rise to a change of magnetostatic energy in materials, resulting in the variation of the domain structure. In view of the induced defects due to radiation damage, the BN height is expected to increase with the neutron irradiation. The individual BN pulse height varies with the different types of domain walls, however it is hard to take into account the different wall types for the irradiated sample. The interaction of the domain walls with irradiation induced defects under the influence of grain boundary and the second-phase precipitates are expected to be significantly complex. Hence, it should not be possible to distinguish the effect of lath or grain size and role of second-phase precipitation on the magnetization process and BN. The BN measurements were made on both unirradiated and irradiated RPV steel having different microstructure partially due to the difference in the steel refining process. The unirradiated samples showed consistent change of BN profiles with microstructure (grain size, carbide morphology, lath width), but the neutron irradiated sample did not show a consistent change with microstructural state.

4. Conclusions

The absence of a trend may be attributed to the different domain wall structure with different microstructure partially due to the steel refining process and resulting in a differing response to irradiation BN showed consistent change with microstructure (grain size, carbide morphology, lath width), but the neutron irradiated sample did not show a consistent change with microstructural state. MBE measurements have been measured on four kinds of RPV steel differing in microstructure as a result of the steel refining process.

5. References

[1] S. Tiitto, Acta. Polytech. Scand., Appl. Phys. Ser., vol. 119, pp. 1, 1997

[2] D.J. Buttle, C.B. Scruby, G.A.D. Briggs, and J.P. Jakubovics, Proc. R. Soc. A, 414, pp. 469, 1987a

[3] D.J. Buttle, C.B. Scruby, J.P. Jakubovics, and G.A.D. Briggs, Phil. Mag., A, vol. 55, pp. 717, 1987c

[4] D. G. Park, C.G. Kim, H.C. Kim, J.H. Hong, and I.S. Kim, "Effect of neuron irradiation on magnetic properties in the low alloy Ni-Mo steel SA508-3,' J. Appl. Phys. vol.81, pp.4125-4127, 1997

[5] S. Saroja, M. Vijayalakshmi, and V.S. Raghunathan, Acta. Metall., vol. 43, pp. 2985, 1995

[6] C.C.H. Lo et al., IEEE Trans. Mag. vol. 33 (5) pp. 4035, 1997

[7] C. Gatelier-Rothea, J. Chicois, R. Fougeres and P. Fleischmann, Acta. Metter, vol. 46, pp. 4873-4882, 1998

[8] M. K. Devine, D.C. Jiles, P.K. Liaw, R.D. Rinhel, D.S. Drinon, Rev. Prog. Quant. NDE, vol.12, pp.1815, 1993

[9] J.T. Buswell, "Analysis of the behavior of advanced reactor pressure vessel steels under neutron irradiation, The UK Programme, UKAEA, April 1983