Drop-Weight Test for Determination of Nil-Ductility Transition Temperature

User's Experience with ASTM Method E 208

Holt/Puzak *editors*

ASTM STP 919

DROP-WEIGHT TEST FOR DETERMINATION OF NIL-DUCTILITY TRANSITION TEMPERATURE: USER'S EXPERIENCE WITH ASTM METHOD E 208

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Foreword

This publication, *Drop-Weight Test for Determination of Nil-Ductility Transition Temperature: User's Experience with ASTM Method E 208*, contains papers presented at the symposium on NDT Drop-Weight Test (E 208 Standard), which was held 28–29 Nov. 1984 in Williamsburg, Virginia. The symposium was sponsored by ASTM Committee E-28 on Mechanical Testing. John M. Holt, consultant, served as editor of this publication, along with P. P. Puzak, consultant, who was chairman of the symposium.

Related ASTM Publications

Fracture Mechanics: Seventeenth Volume, STP 905 (1986), 04-905000-30

Fracture Mechanics: Sixteenth Symposium, STP 868 (1985), 04-868000-30

Through-Thickness Tension Testing of Steel, STP 794 (1983), 04-794000-02

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

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Overview

In November 1984, ASTM Committee E-28 on Mechanical Testing held an international symposium to discuss users' experience with the ASTM Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels (E 208). The objectives of the symposium were to determine (1) unusual material behavior; (2) advantages of the test, including correlations of the results with service experience and other tests; (3) shortcomings of the method; and (4) unique testing equipment or experimental techniques. Of the twelve papers presented at the symposium, nine have been published in this Special Technical Publication. These nine papers cover the symposium objectives well; it is interesting to note that most of the authors found shortcomings in ASTM Method E 208-81 (the then current version of ASTM Method E 208) and made recommendations to overcome these shortcomings. The task group of ASTM Committee E-28 charged with oversight for the drop-weight (DW) test was aware of several of these deficiencies and had initiated appropriate action—for example, the crack-starter weld bead was changed to a single stringer bead without weave to minimize the heat input and thereby reduce the possibility of tempering the base metal at the notch. There were other deficiencies, however, of which the task group was not aware, and these are currently being studied.

The opening paper, by *Ando et al,* presents the results of a study of welding parameters—welding current, preheating, shape of the bead, and other parameters—which shows that the welding current is the most influential parameter. In this study, the authors tested a sufficient number of specimens to make probability statements about the occurrence of nil-ductility transition (NDT) at specific temperatures.

The second paper, by *Satoh et al,* also shows the importance of the welding current and points out how heat sinks can influence the NDT temperature by changing the cooling rate of the heat-affected zone (HAZ), thereby producing a tough or not-so-tough microstructure. The authors indicate that good correlation between the NDT and Charpy impact transition temperatures can be obtained. (The editors caution that the correlations are probably based on the use of the Japanese Industrial Standard Charpy striker geometry and not on the ASTM test geometry; thus, the absolute values of the constants may be slightly affected.)

The next three papers, by *Onodera et al, Lundin et al,* and *Koshizuka et* *al,* discuss the effect that the crack-starter weld bead has on the NDT temperature. They, too, demonstrate that the then standard two-pass technique of laying down the bead can temper the HAZ, which, in some materials, can significantly increase the toughness (lower the NDT temperature). (Because of these and other similar studies, ASTM Method E-208 was revised in 1984, prior to this symposium, to require that only the one-pass method be used when laying down the crack-starter bead.)

Koshizuka et al, in the fifth paper, also go on to estimate the NDT temperatures from K_{Id} values obtained from instrumented precracked Charpy specimens; they obtained good agreement.

The sixth paper, by *Hartbower,* points out the difficulties in interpreting the results when there is a through-thickness toughness gradient in the material and the DW test specimen is taken from the surface, as specified by ASTM Method E 208-69(1975). This gradient also manifests itself in the visual determination of whether the top-surface crack extends to the specimen edges and thus whether or not the specimen is "broken." The author suggests heat tinting the specimen after the test and then breaking it open to examine the extent of the original fracture.

Low and Early present the results of DW tests using specimens with curved surfaces, which had been removed from plates that were curved in two orthogonal directions. Their results indicate that the effect of the curvature is greater when the crack-starter weld is on the tension surface than when it is on the compression surface; however, they caution that the shift in NDT temperature may be masked by the inaccuracy associated with the E 208 test method.

Because many material specifications couple DW transition temperatures with Charpy V-notch transition temperatures to obtain a "reference temperature," data contained in a data bank were investigated by the authors of the eighth paper, *Oldfield and Server,* using computer techniques to determine reference temperatures for several steels. Predictions by the model of the NDT temperature and reference NDT temperature from dynamic fracture toughness data are in excellent agreement with measured values. They also show the dependency of the upper-shelf Charpy energy values in setting the reference temperature.

The final paper discusses the DW test from a fracture mechanics point of view. The author, *Sumpter,* postulates that shear lip development may be the common factor, which explains the empirically observed correlation between K_{Id} and the DW nil-ductility transition temperature.

The end of this volume contains an appendix, in which ASTM Method E 208 is reprinted in full. The version printed, E 208-85, was approved in 1985 and is the most recent version of this standard.

The editors of this publication would like to thank the authors and presenters at the symposium for their papers and the continuing discussion. A thank-

you is also extended to those who reviewed the manuscripts, and to the editors at ASTM, especially Helen Mahy, who saw to it that this Special Technical Publication was published.

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Contents

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Effect of the Brittle-Bead Welding Conditions on the Nil-Ductility Transition Temperature

REFERENCE: Ando, Y., Ogura, N., Susukida, H., Satoh, M., Tanaka, Y., and Ando E., **"Effect of the Brittle-Bead Welding Conditions on the Nil-Ductility Transition Temperature,"** *Drop-Weight Test for Determination of Nil-Ductility Transition Temperature: User's Experience with ASTM Method E 208, ASTM STP 919*, J. M. Holt and P. P. Puzak, Eds., American Society for Testing and Materials, Philadelphia, 1986, pp. 1-15.

ABSTRACT: The drop-weight test plays an important role in determining the reference nil-ductility transition temperature (RT_{NDT}), which indicates the fracture toughness characteristics of ferritic steels in the design of nuclear power plant components. In recent years, however, it has been shown by various papers that the nil-ductility transition temperature (NDTT) obtained by this test depends on such parameters as the welding conditions of the crack-starter bead, notch location, and other factors.

In this paper, the authors have investigated the scattering of NDTT and discuss the necessity of revising Japan Electric Association Code 4202, The Method of Drop-Weight Testing of Ferritic Steels, under the auspices of the Japan Electric Association; this standard refers to the practical welding conditions employed by many research organizations in Japan.

From the results of this study on the effects of such parameters as the welding current, preheating, interpass temperature, shape of bead, welding speed, and notch location on NDTT, the authors conclude that the most influential factor to be determined for prevention of wide scattering of NDTT is the welding current. Based upon these results, standard JEAC 4202 was revised on 20 March 1984.

KEY WORDS: nil-ductility transition temperature, drop-weight test, scattering, crack-

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starter bead, welding current, notch location, preheating, ferritic steel, nuclear power plant components, ASTM standard E 208

The drop-weight test has played an important role in determining the reference nil-ductility transition temperature (RT_{NDT}), which represents the fracture toughness of ferritic steels in the design of nuclear power plant components. In recent years, however, several papers have been presented stating that the nil-ductility transition temperature (NDTT) depends on such parameters as the welding conditons of the crack-starter bead, notch location, and other factors [*1–5*].

As clearly shown in these papers, the phenomenon of NDTT scattering has been considered to relate closely to the toughness of the heat-affected zone formed by crack-starter bead welding. Since the drop-weight test is to be conducted at intervals of 5°C using several test specimens, it may be difficult to eliminate the scattering entirely. However, in view of its influence on the reliability of the design of nuclear power plant components, a difference in NDTT of more than 25°C, as shown in Table 1 [*1,3*], should be avoided. Although the question leaves room for discussion, it would be desirable to limit the difference in NDTT to within 10°C.

TABLE 1—*Effect of the welding conditions of the crack-starter bead on NDTT (from Refs* 1 *and* 3*).*

Material Tested : A508 Cl.3

Crack-Starter Bead \ Test Temp. °C				−45	−40	−35	−30	−25	−20	−15	NDTT °C
A	Standard (2 pass)	160A	FOX-D	●	○ ○		○				−45
B	Standard (2 pass)	180A	FOX-D	●		● ○	○ ○				−35
C	Standard (2 pass)	200A	FOX-D				● ○	● ○	○ ○		−25
D	Standard (2 pass)	160A	Murex-H	●	●	○ ○					−40
E	Standard (2 pass)	180A	Murex-H				●	○ ○			−30
F	1 Pass	180A	FOX-D				●	●	●	○ ○	−20
G	1 Pass	200A	FOX-D				●	●	●	○ ○	−20
H	Fatigue Crack Notch	−	−			●		●	●	○ ○	−20

Electrode··· FOX-D:FOX DUR 350, Murex-H:Murex Hardex N, ● : Break ○ : No Break

According to the papers referred to [*1–5*], the parameters that are supposed to be influential in determining the phenomenon of scattering show a wide range of changes: that is, some of the data differ widely from those of the welding conditions actually adopted.

In this paper, the authors have investigated the phenomenon of scattering of NDTT by referring to the welding conditons employed in practice by many research organizations and have discussed the problem of whether or not it would be necessary to revise the provisions of the Method of Drop-Weight Testing of Ferritic Steels, Japan Electric Association Code (JEAC) 4202, which was enacted in 1970 and refers to the ASTM Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels (E 208-69).

Effect of Parameters on NDTT

Welding Current

Table 1 [*1,3*] and Table 2 [*2*] show the effect of welding conditons of the crack-starter bead on NDTT. These tables show that NDTT varies over a range of 25°C, depending on the value of the welding current. As the result of tests for ASTM A508 Class 2 and 3 steels, the lower NDTTs are given when the welding current is lower, and the difference in NDTTs between specimens welded at 160 A and those at 200 A reaches 25°C. However, if the result is rearranged by limiting the welding current within the range of 180 to 210 A, which is recommended by the provisions of Standard JEAC 4202, the maximum difference in NDTT is less than 10°C, as shown in Table 3.

Tables 4 and 5 [*6*] show NDTTs obtained when the bead was welded at between 180 and 210 A for ASTM A508 Class 3; A533 Grade B, Class 1; A533 Grade A, Class 1; and A516 Grade 70 steels. In this test, the test specimens were prepared from the different thickness locations of the steels and the weld metals, and Murex Hardex N and NRL-S electrodes, recommended in ASTM Method E 208-81, were used as the electrodes. According to the result, the maximum difference in NDTT remains within 10°C.

Figure 1 [*7*] shows the results of tests carried out for 80 test specimens cut out from an A508 Class 3 steel at the same thickness location of the steel. The test specimens were divided into two lots of 40 specimens each and the crack-starter beads were welded at 180 A for one lot and at 200 A for the other. Two specimens, one from each lot, were tested at the same temperature at intervals of 5°C, and the results are shown in Fig. 1 divided into "break" and "no break" categories. Specimens welded at 180 A showed a "no break" trend. Figure 2 [*7*] shows the results of calculations of the probability with which each temperature becomes the NDTT under the test conditions used. For the specimens welded at 200 A, NDTTs lie in the range of −40 to −30°C with a scattering of 10°C; for the specimens welded at 180 A, NDTTs lie in the range

TABLE 2—*Effect of the welding conditions of the crack-starter bead on NDTT (from Ref 2).*

Material Tested : A508 Cl.2

	Welding Sequence	Amperage A	Test Temperature °C											NDTT °C
			-50	-45	-40	-35	-30	-25	-20	-15	-10	-5	0	
A	2 pass	150/160	●	●	○○		○							-45
B	2 pass	170/180	●	●	○○		○							-45
C	2 pass	190/200			●	●	●	○○						-30
D	1 pass	150/160					●				●	●	○○	-5
E	1 pass	170/180					●				●	○○	○	-10
F	1 pass	190/200					●				●	○○	○	-10

Electrode : FOX DUR 350 ● : Break ○ : No Break

TABLE 3—*Effect of the welding conditions of the crack-starter bead on NDTT (from Ref 7).*

Material Tested : A508 Cl.3

Amperage(A)	Polarity	Electrode	Test Temperature °C				NDTT °C
			-35	-30	-25	-20	
180A	AC	Fox Dur 350	● ○	○ ○			-35
200A	AC	Fox Dur 350		● ○	● ○	○ ○	-25
180A	AC	Murex Hardex N		●	○ ○		-30

●: Break ○: No Break