SIEMENS

(10)

Material Testing with Reconstituted Specimens at Siemens Hot Cell Laboratory

R. Hoffmann
G. Hofmann
E. Keim
R. Langer

Paper to be presented at the Plenary Meeting
of the European Working Group
„Hot Laboratories and Remote Handling"
June 5 and 6, 1997 at Studsvik, Nyköping, Sweden

Material Testing with Reconstituted Specimens at Siemens Hot Cell Laboratory

by R. Hoffmann, G. Hofmann, E. Keim, R. Langer

Abstract

After a short introduction of the Siemens Hot Cell Laboratory facilities at Erlangen the fabrication of reconstituted specimens and their qualification is described.

Test results of reconstituted specimens of the Charpy and subsize impact type are presented and compared to data acquired by testing original Charpy specimens.

Comparing index temperatures of compact and subsize specimens, a simple correlation function is shown which converts data from subsize specimens to data derived from compact specimens.

Thus, the use of subsize and/or reconstituted Charpy specimens is warranted in cases where only small amounts of material to be tested are available.

Introduction

The Siemens Hot Cell Facility has been operative for over 30 years. Its main investigations and examinations have been in the field of NPP irradiation programs (testing of material properties by tension, impact, drop weight tests to be used for the mandatory safety analysis according to KTA 3201.2), failure analysis (assessment of failure causes by metallographic techniques and chemical analyses) and material development of reactor grade steels, fuel and fuel rods, namely by examination of oxide layers, hydride distribution, and fission product distribution.

The Hot Cell Facility was enlarged and upgraded several times, especially the material testing section. A new working area was opened in 1980 when an electron beam welding machine was installed in a new hot cell to fabricate compound, i.e. reconstituted specimens ready for testing.

The Siemens Hot Cell Facility

The Siemens Hot Cells were erected 1964 - 66 as integral part of the Radiochemical Laboratory, situated at the Corporate Research Center in Erlangen, Germany. They were designed for post irradiation examinations on nuclear fuel and reactor material, and have been used for chemical and radiochemical analysis, destructive material testing and metallography. According to their specific use, they are divided into three categories:

- 2 hot cells with 90 cm of heavy concrete shielding
- 4 material testing cells with up to 20 cm of lead shielding
- 5 metallography/chemistry cells with up to 15 cm of lead shielding.

The two hot cells are primarily used for dismantling irradiation capsules and preparing specimens or samples for further investigations (mainly by cutting, milling, drilling and the like).

The *four material testing* cells offer 12 working stations, each being equipped with a 50 cm x 40 cm shielded window and one or two remotely controlled manipulators.

The equipment in the *material testing cells encompasses:*

- miniature impact testing machine with instrumented 15 Joule hammer, test temperatures: - 150 °C to + 275 °C
- standard impact testing machine with instrumented 300 Joule hammer, test temperatures: - 150 °C to + 275 °C
- multi-purpose miniature tension testing machine of up to 5 kN for alternate tension-compression load test, test temperatures: - 196 °C to + 275 °C
- resonance pulsator of up to 20 kN, 250 Hz for fatigue precracking of fracture mechanics specimens and determination of crack growth rate
- multi-propose tension testing machine of up to 200 kN, for alternate tension-compression load test, test temperatures: - 196 °C to + 300 °C
- multi-purpose tension testing machine of up to 600 kN, test temperatures: - 150 °C to + 275 °C

- Pellini machine for drop weight test specimens, test temperatures: - 150 °C to + 275 °C
- stereo periscope with photographic and video equipment for documentation of fracture surfaces
- video systems for fracture surface evaluation and crack propagation measurement
- annealing equipment for annealing irradiated specimens at temperatures of up to 600 °C
- electron beam welding machine for production of composite specimens with irradiated inserts of up to size CT 200 including demagnetization equipment with spool inside dimension 230 mm x 230 mm and 230 mm x 1000 mm.

The unirradiated baseline specimens are tested on equivalent testing devices as those available in the materials testing cells.

The five chemistry/metallography cells with plexiglass boxes and 10 to 15 cm thick lead walls are available for specimen/samples with activities of up to approximately 10^{12} Bq.

The equipment consists of:

- hardness tester (Micro-, low load-, Macro-)
- grinding and polishing machines, etching equipment
- cutting machinery (diamond- and diamond wire-, belt-)
- stereo microscopes
- complete video equipment with picture processing facility
- photo lab

The cells are connected to the concrete cells by a remotely controlled transport mechanism.
Fume hoods are available for preparation of less radioactive specimens (≤ 20 mSv/h) following radiation protection precautions (mobile shielding, hand, face, and respiratory protection).

Fabrication of Reconstituted (Compound) Specimens

During the last 15 years a major branch of work in the hot cells has been the fabrication of compound specimens by electron beam welding (EBW). By use of an EBW-machine of the type Leibold-Heraeus ESW 1001/15 with maximum current capability of 12,7 mA and demagnetization spool inside dimension of 230 mm x 230 mm and 230 mm x 1000 mm, (irradiated) compound specimens from subsize impact to CT 200 can be fabricated with high precision, ready for testing without the need of post-welding machining.

The maximum welding depth with this machine is 108 mm, therefore CT200 compound specimens can be fabricated by two-side-welding. The welding process has been qualified in the frame of accreditation to DIN EN 45001/2 in 1993.

So far more than 2500 irradiated and non-irradiated compound specimens of the impact, Pellini, WOL-X and CT type have been welded and tested of which about 2000 were of the Charpy type [2].

In the following overview an account of the qualification of composite Charpy and subsize impact (KLST) specimens is given.

Qualification of compound Charpy specimens

Examinations of compound Charpy specimens (all of them EB welded) showed that specimens with insert lengths of > 12 mm produced identical test results to compact Charpy specimens, namely identical load-displacement records and derived energy-temperature curves [1]. ASTM guide E1253-88 recommends therefore a minimum insert length of 14 mm.

Smaller inserts of 10 mm length have the advantage of independent orientation and a greater number of inserts out of broken halves. However, they tend to decrease toughness properties, mainly in the upper transition and upper shelf region [2, 4, 5].

The following qualification tests with 22 NiMoCr 3 7 base material (original and tempered condition) and also weld material were performed [6].

Temperature tests:

An important criterion for qualification of 10 mm inserts is the temperature distribution in the insert during EB welding since annealing effects in irradiated material must not take place. For these measurements, thin thermocouples were spot welded at different locations of the insert. To keep temperatures low, end tabs and insert were mounted alongside chilling blocks, and after welding the first seam, the whole apparatus was cooled to room temperature before welding the second seam.

The test results show that in the center region of the insert the temperature stays just below the operating temperature of 300 °C. It must be mentioned, however, that even at slightly higher temperatures annealing will not take place to a considerable degree because of the rapid cooling of the welding apparatus after welding (only seconds above the original fabrication annealing temperature).

Hardness tests:

Hardness tests (HV5) were performed on the broken halves of base metal and weld metal specimens. In both cases, the heat affected zone (HAZ) is smaller than 1.5 mm, so a region of about 7 mm of the center insert region is not affected [1].

However, because of the harder HAZ, the plastic deformation is reduced as the plastic zone reaches the HAZ. This happens only in the upper transition or upper shelf region, so the decreased energy at these regions can thus be explained [4, 6].

In order to approximate irradiation induced hardening, the stud ends, made of non-irradiated base metal, were tempered. It was shown by hardness measurements across the weldment, that tempered base material is an appropriate stud end material for irradiated weld [6].

Qualification of compact and compound subsize impact specimens

Subsize impact specimens as standardized to DIN 50115 (KLST-specimens) were also tested in regard to comparability of compact and compound specimens and in regard to correlation between subsize and normal (Charpy) size [5]. This time using a stud welding process, compound subsize specimens with insert lengths of 8 mm of non-irradiated and 12-18 mm of irradiated base metal and weld metal inserts were fabricated (at VTT, Finland) and tested [6, 7].

Temperature and hardness measurements of 8 mm inserts show a HAZ of 1 mm in the insert while the distance between the A_1 transformation points is about 6 mm [3].

The results as shown in the energy-temperature curves show good to reasonable agreement between compact and compound subsize specimens [6].

A simple correlation function which correlates index temperatures of Charpy and subsize impact (KLST) specimens was found by using more than 2500 experimental data to be

$$T_{transition}\ (\text{subsize}) = T_{transition}\ (\text{Charpy}) - 65\ K$$

References

[1] Klausnitzer, E. N. and Hofmann, G., „Reconstituted Impact Specimens with Small Inserts," *Effects of Radiation on Materials:* 15th International Symposium, ASTM STP 1125, R. E. Stoller, A. S. Kumar, and D. S. Gelles, Eds., American Society for Testing and Materials, Philadelphia, 1992, pp. 76 - 90

[2] Klausnitzer, E., „Electron-Beam-Welded Compound Specimens for Fracture Mechanics Investigations", *Proceedings of 22nd National Symposium on Fracture Mechanics,* American Society for Testing and Materials, Atlanta, 1990

[3] Klausnitzer, E., Kristof, H., and Leistner, R., „Assessment of Toughness Behavior of Low Alloy Steels by Subsize Impact Specimens," *Proceedings of 8th International Conference on Structural Mechanics in Reactor Technology,* Brussels, Belgium, August 1985

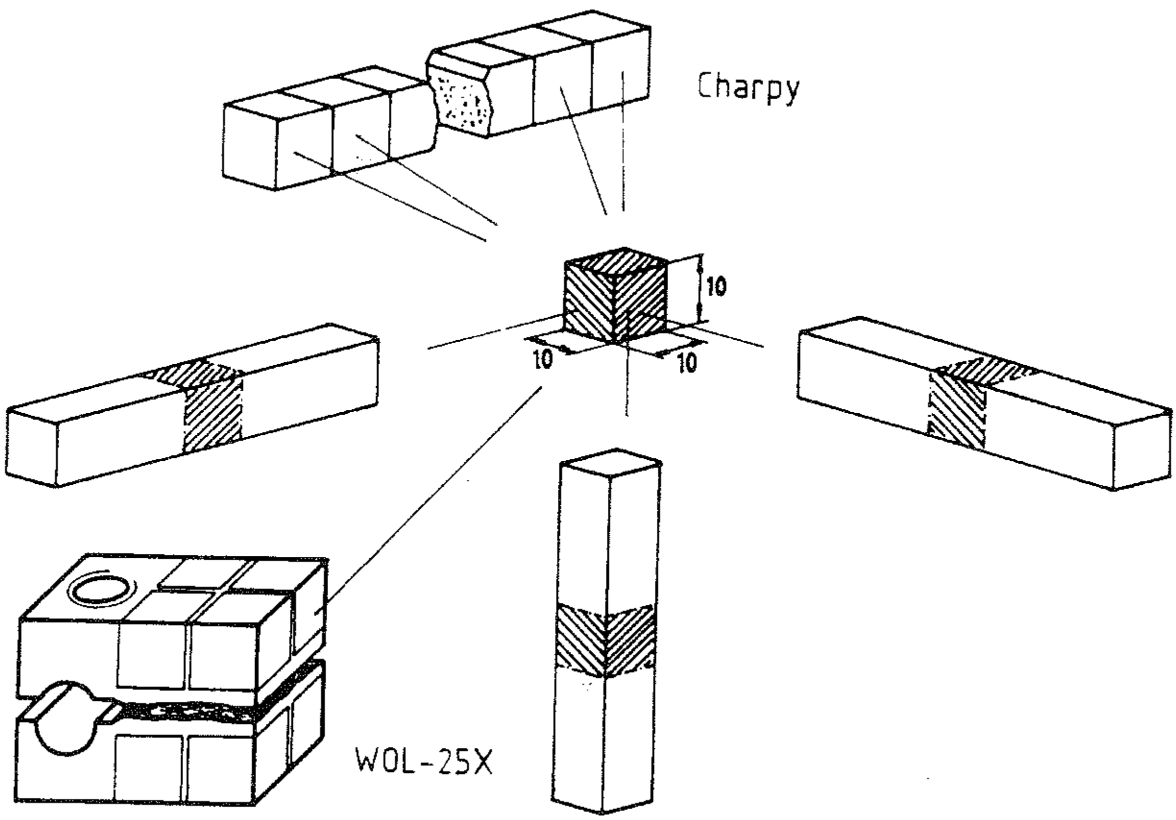
[4] Klausnitzer, E., „Detailed Investigations on Reconstituted Charpy Specimens with Insert Length down to 10 mm", *Workshop on Experience with Testing Reconstituted Charpy Specimens,* ASTM E10 Winter meeting on January 30, 1991, San Diego

[5] Klausnitzer, E., „Experience with Micro-Specimens for Mechanical Investigations of Local Inhomogeneities in Structural Materials, Weldments and Thin-Walled Structures", *Fracture Behaviour and Design of Materials and Structures*: 8th European Conference on Fracture, Turin, 1990

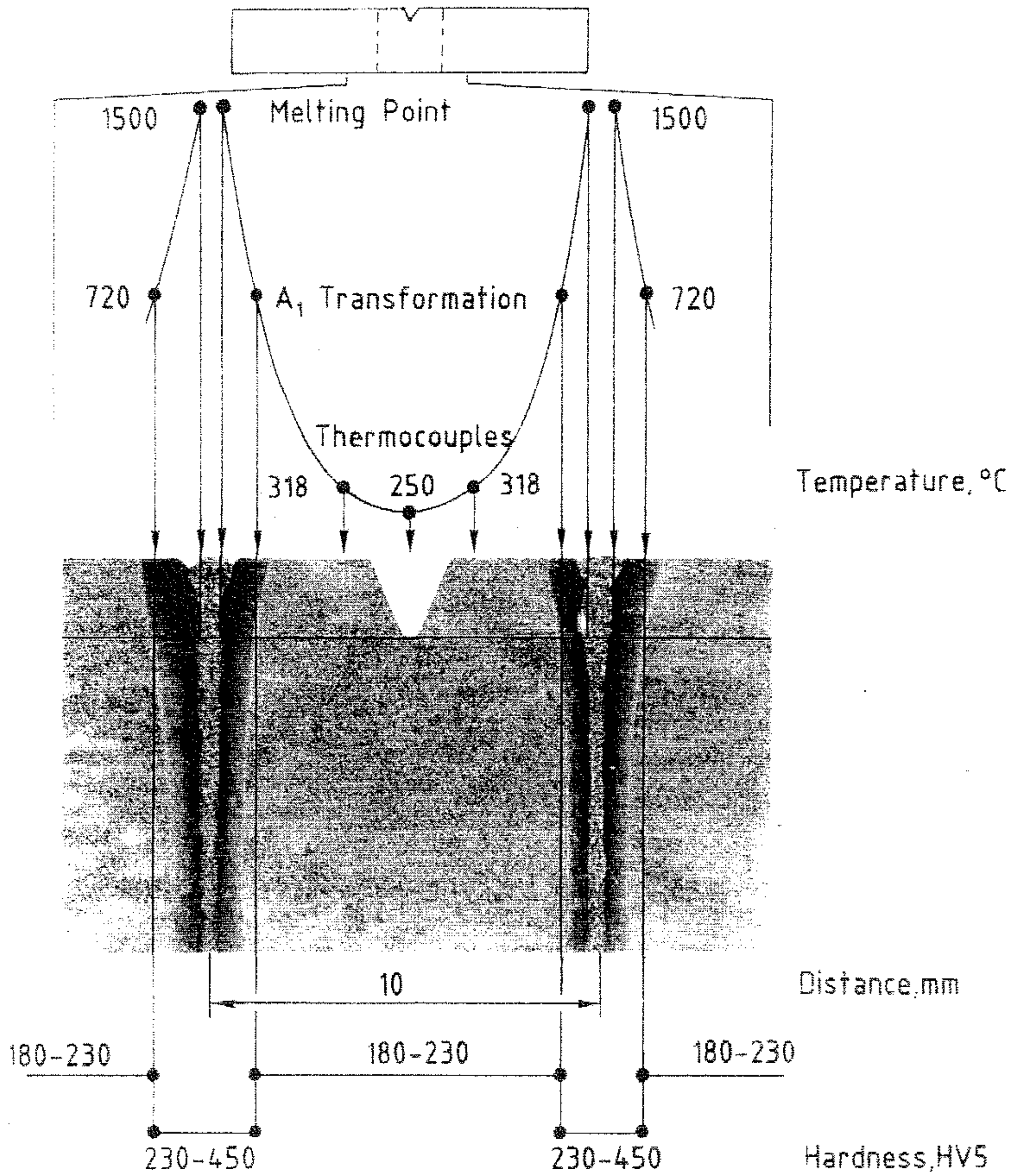
[6] Keim, E., Langer, R., Hofmann, G., „Comparison of Compact, Reconstituted and Subsize Charpy Specimens", *Small Specimen Test Techniques,* ASTM STP 1329, W. R. Corvin, S. T. Rosinski, E. von Walle, Eds., American Society for Testing and Materials, 1997

[7] Leitz, C., Pastor, D., Valo, M., „Recovery Annealing and Subsize Specimen Testing for Units I and II of NPP Nord (Greifswald)", *Seminar über Strahlenbeeinflussung von Reaktordruckbehältern,* GRS Köln, 1990

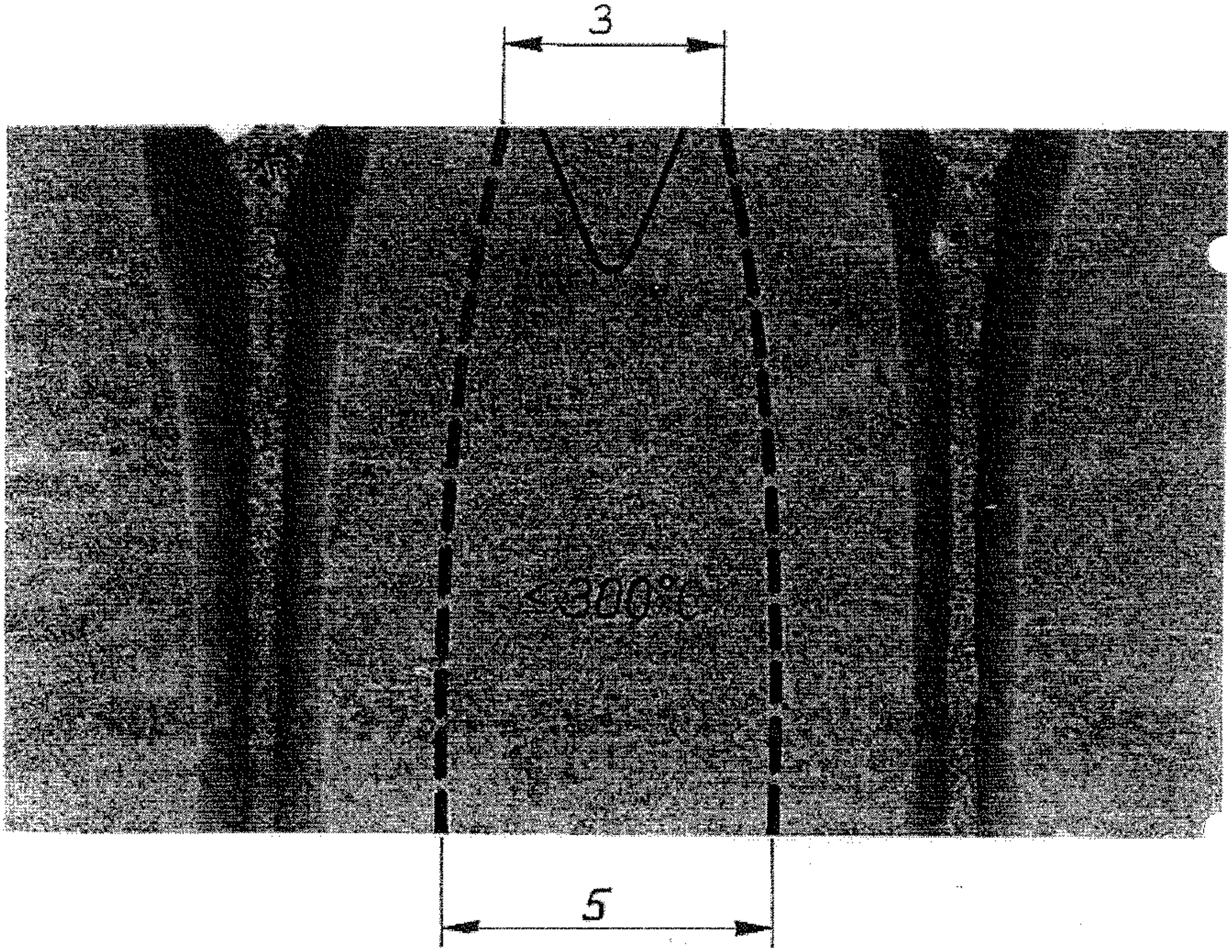
Reconstitution of Charpy specimens
from broken Charpy or WOL-X specimens



Temperature distribution during electron beam welding

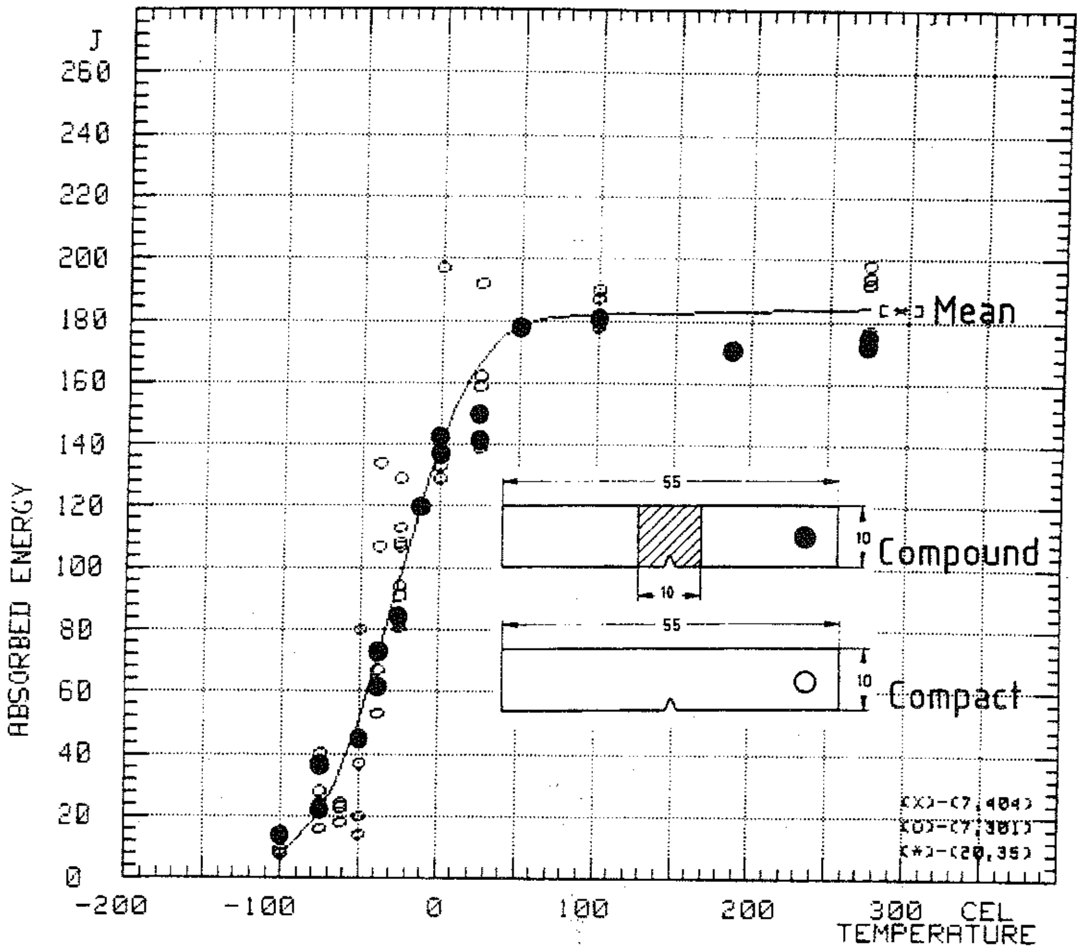


Region below 300°C in an electron beam welded specimen

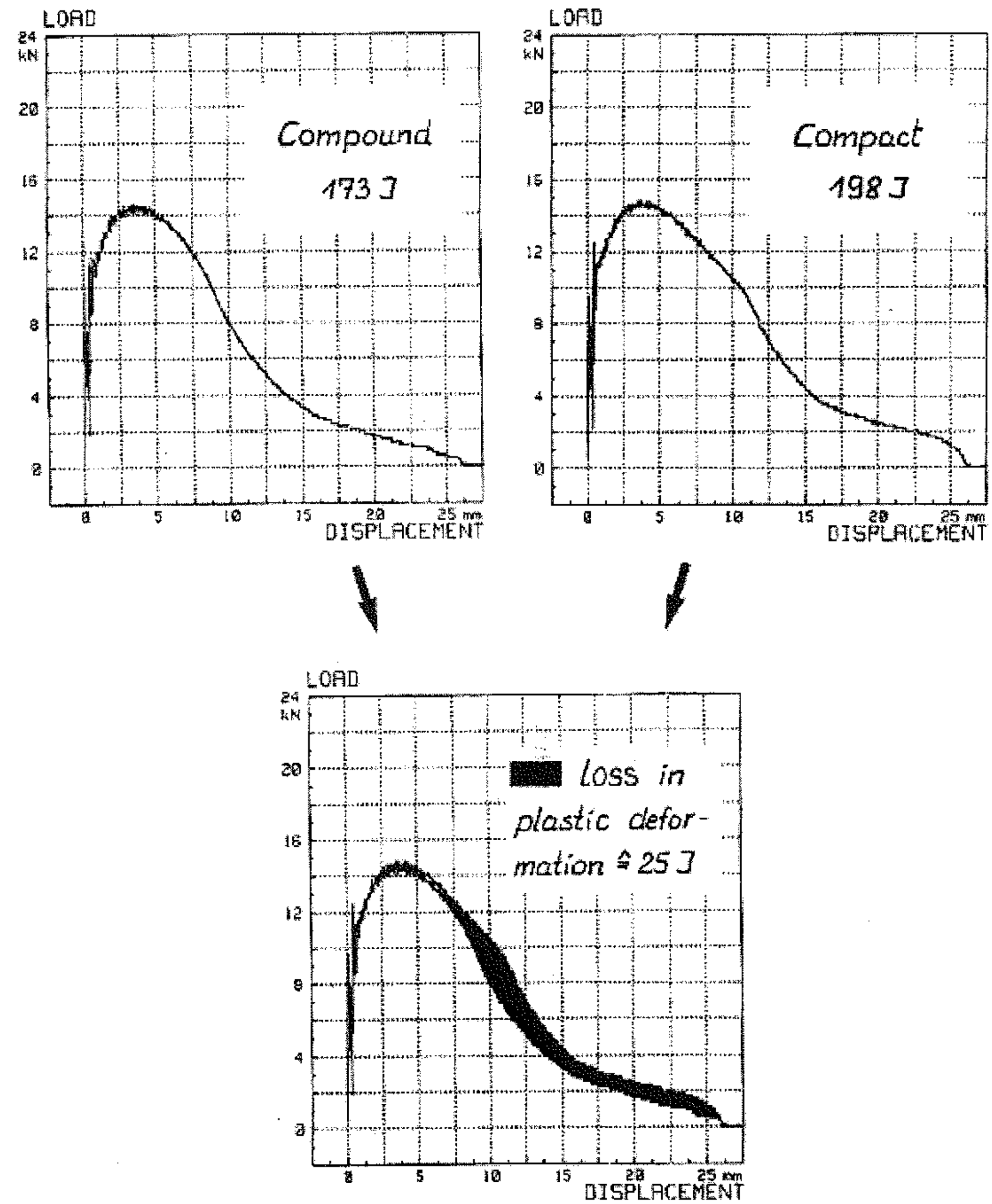


SIEMENS

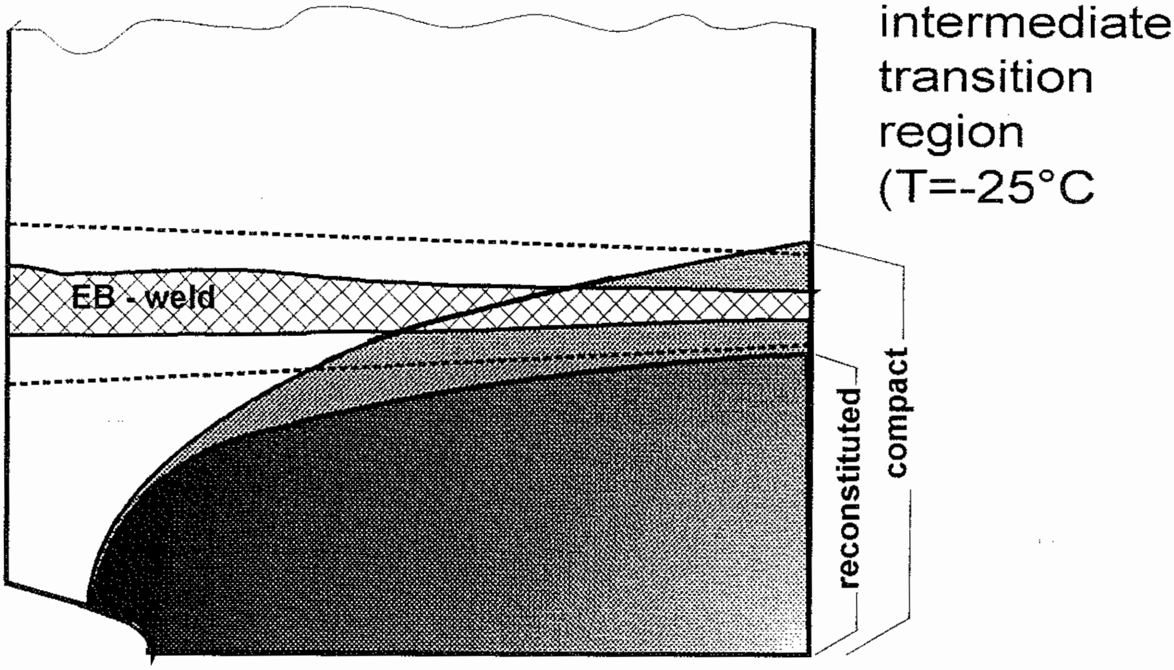
Difference between compact and compound specimens in the upper shelf region

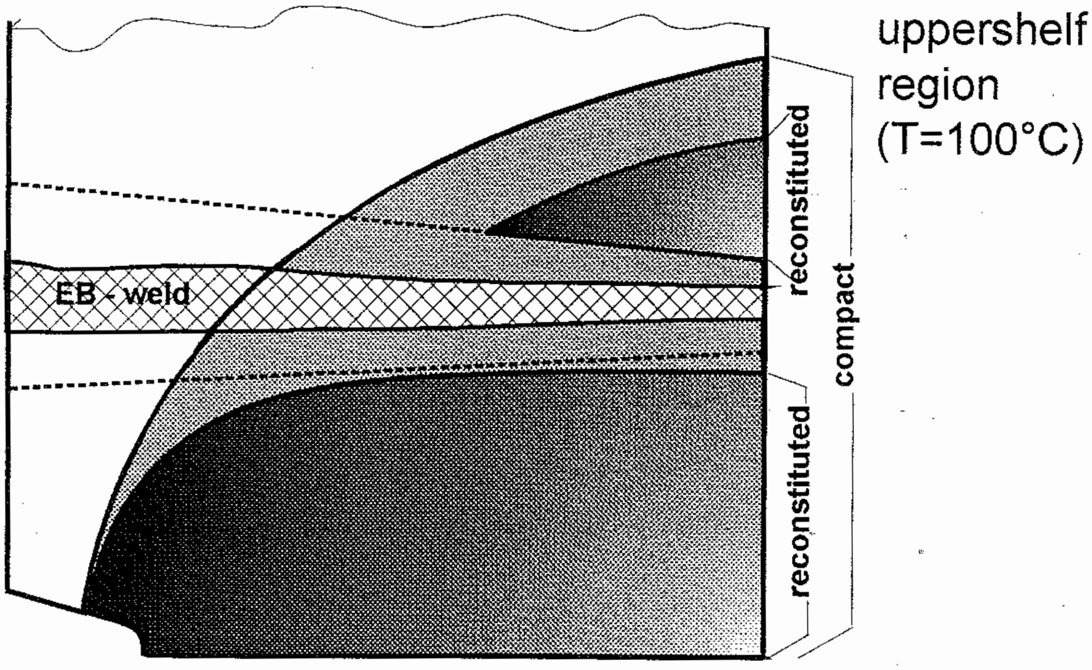


Explanation of different upper shelf energies for compact and 10 mm insert compound specimens

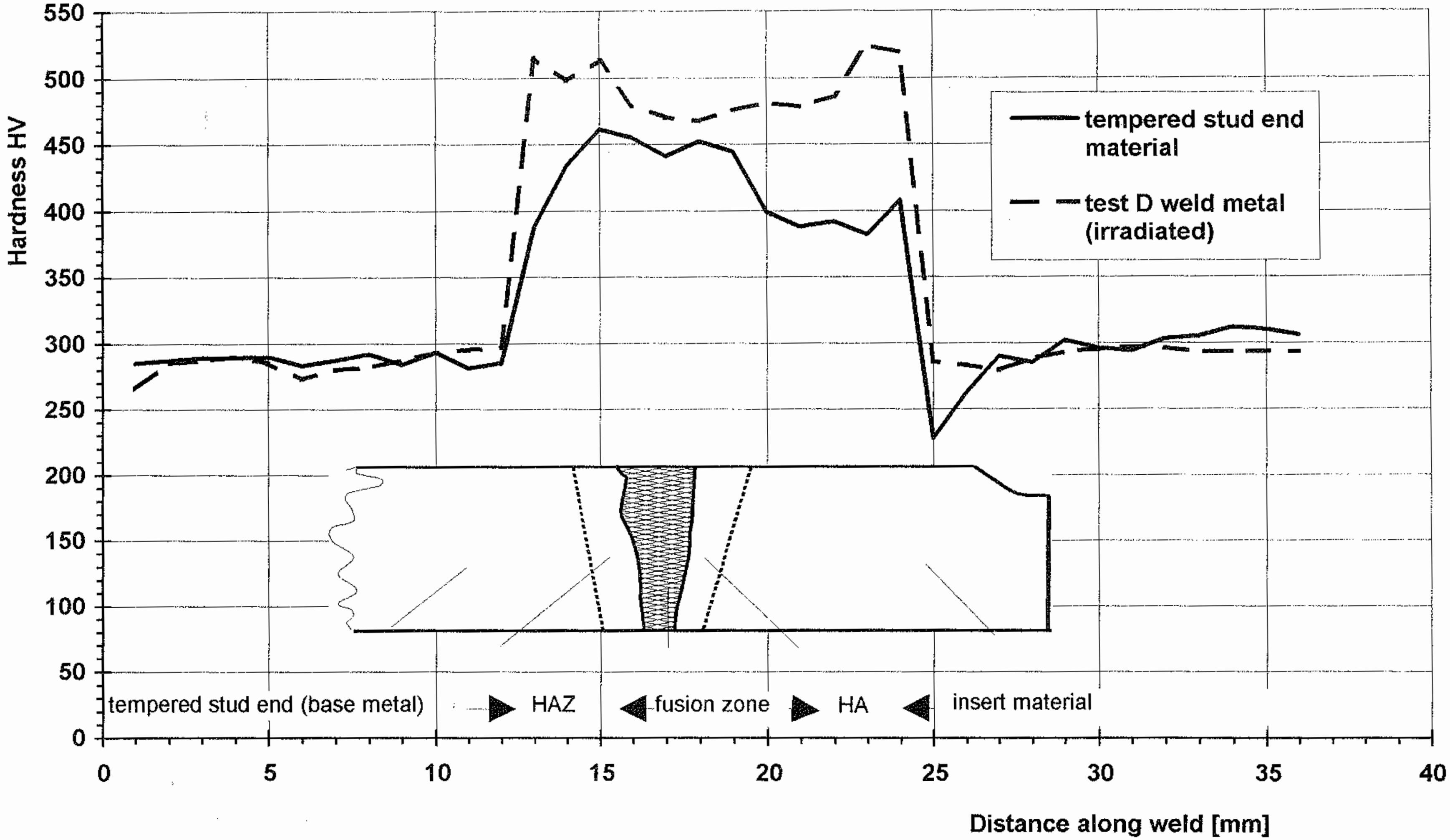


SIEMENS



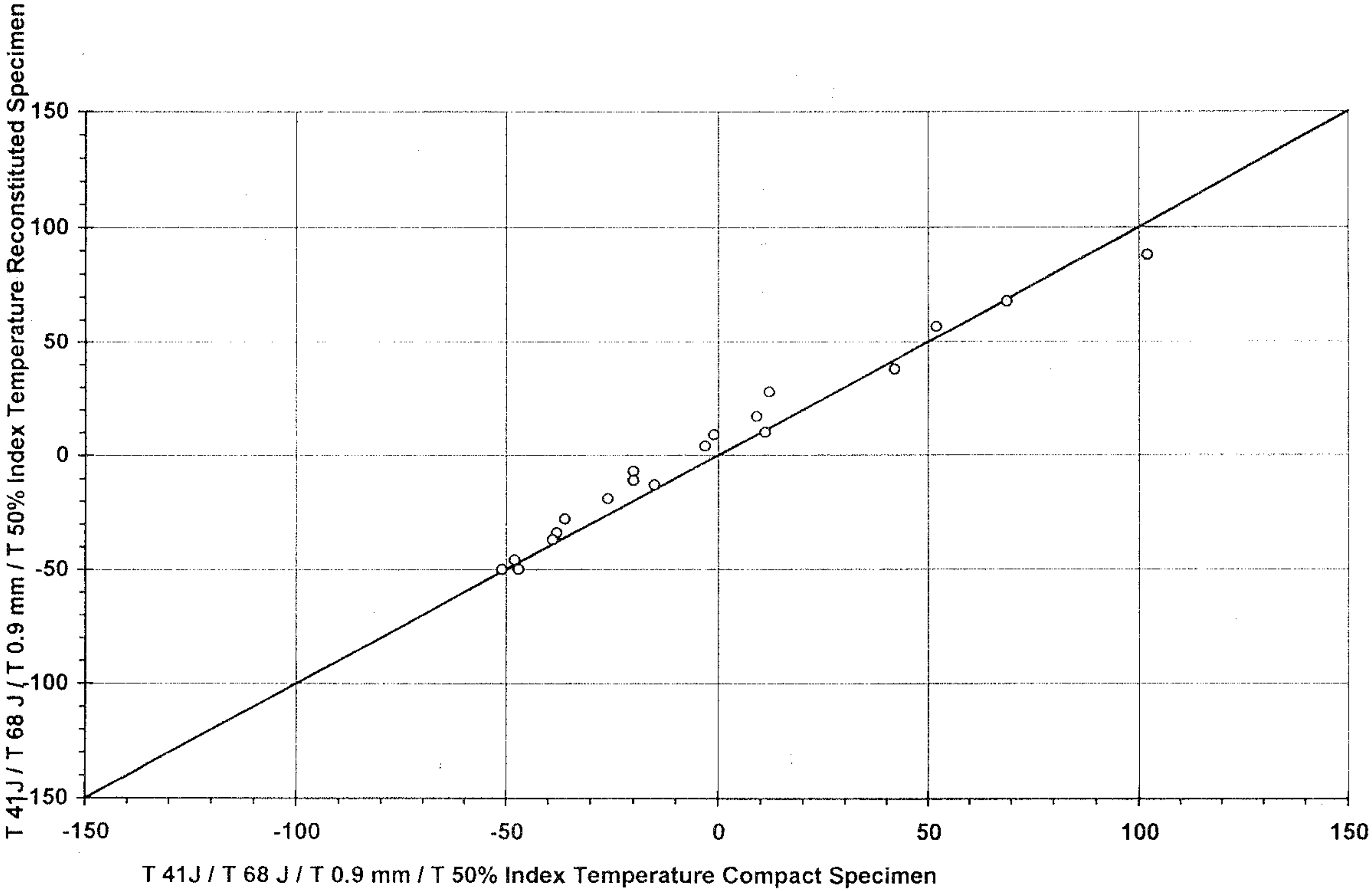


Comparison of the Plastic Zones of Compact and Reconstituted Specimens measured by Hardness



Hardness Distribution after EB Welding, Weld Metal (irradiated conditon)

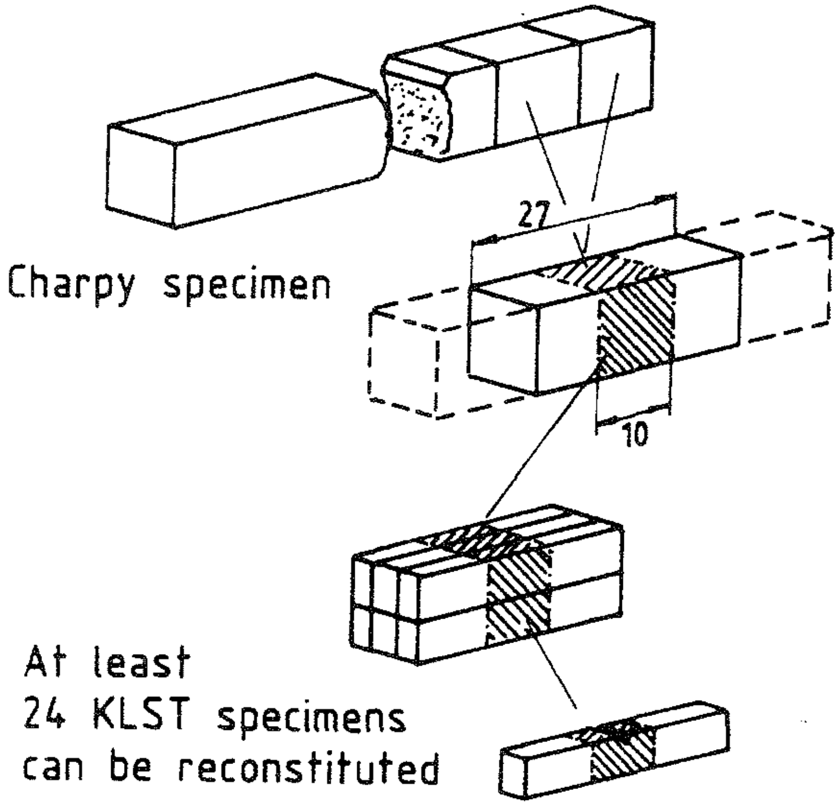
SIEMENS



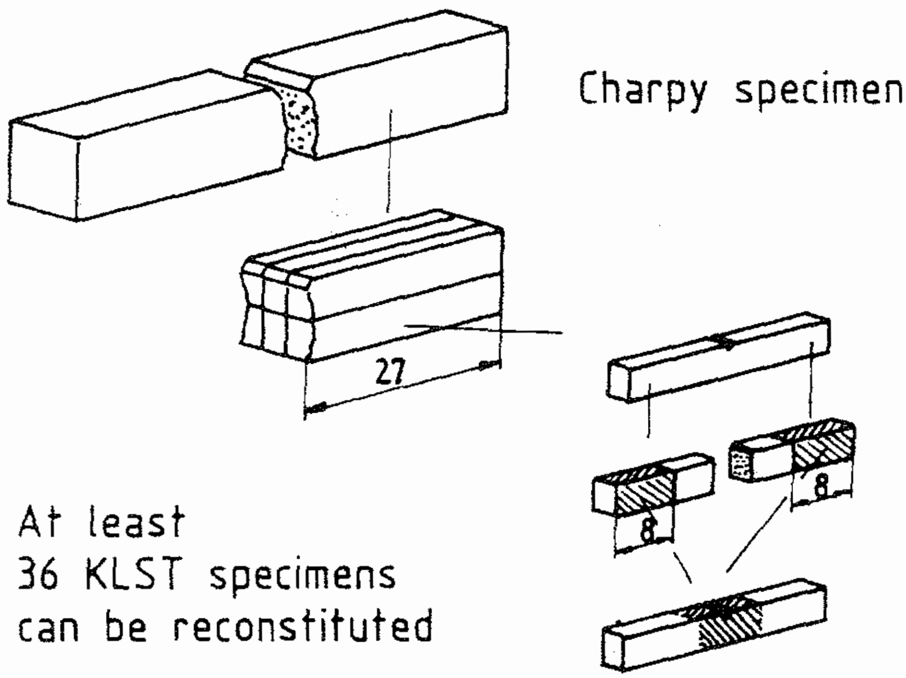
Comparison of Index Temperatures for ISO-V Specimens

ASME3.XLS/20.12.1996
NT13/Keim E.
Ki-01-4

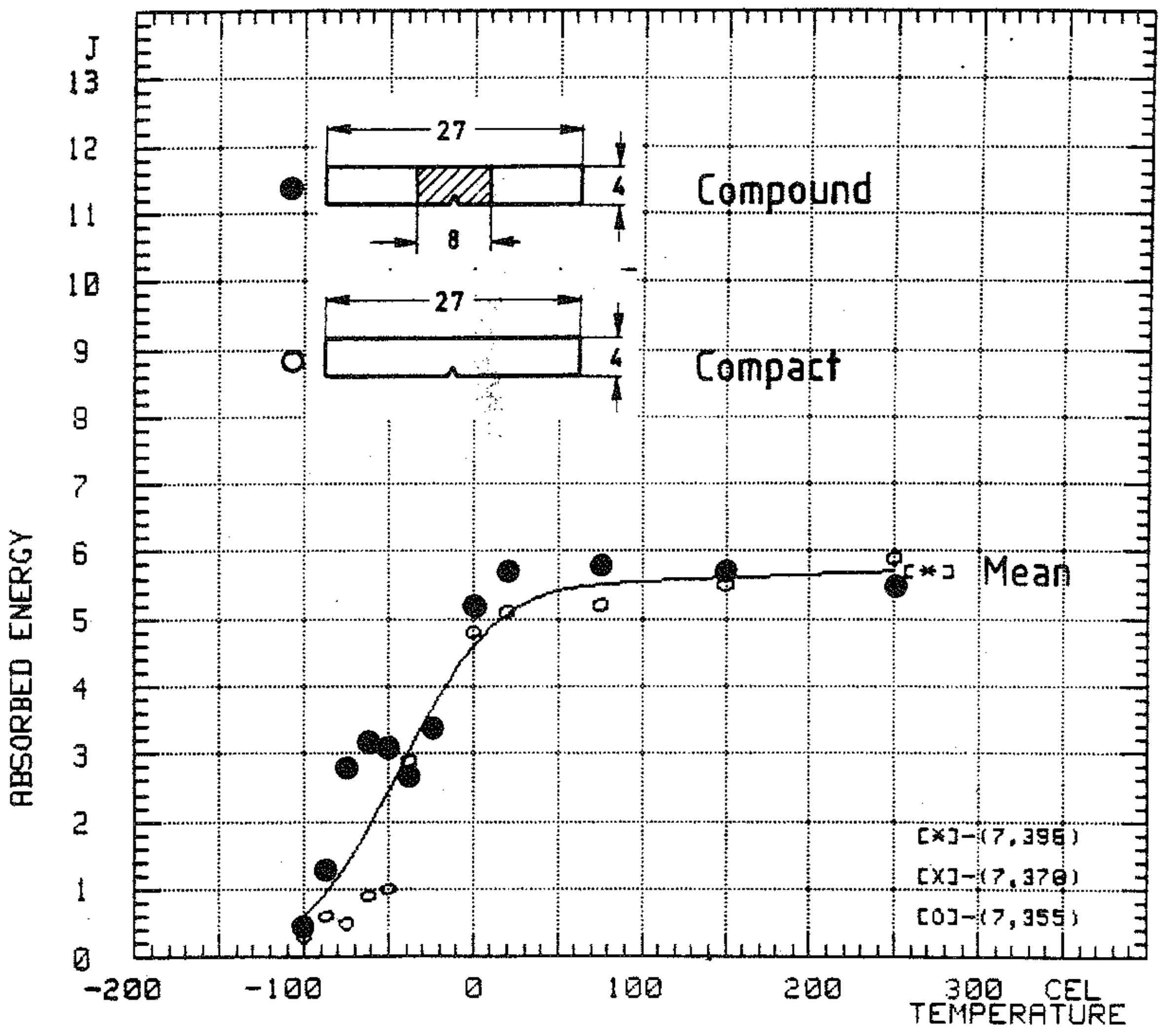
Reconstitution of subsize impact (KLST) specimens from broken Charpy specimens by welding 10 mm x 10 mm cross sections



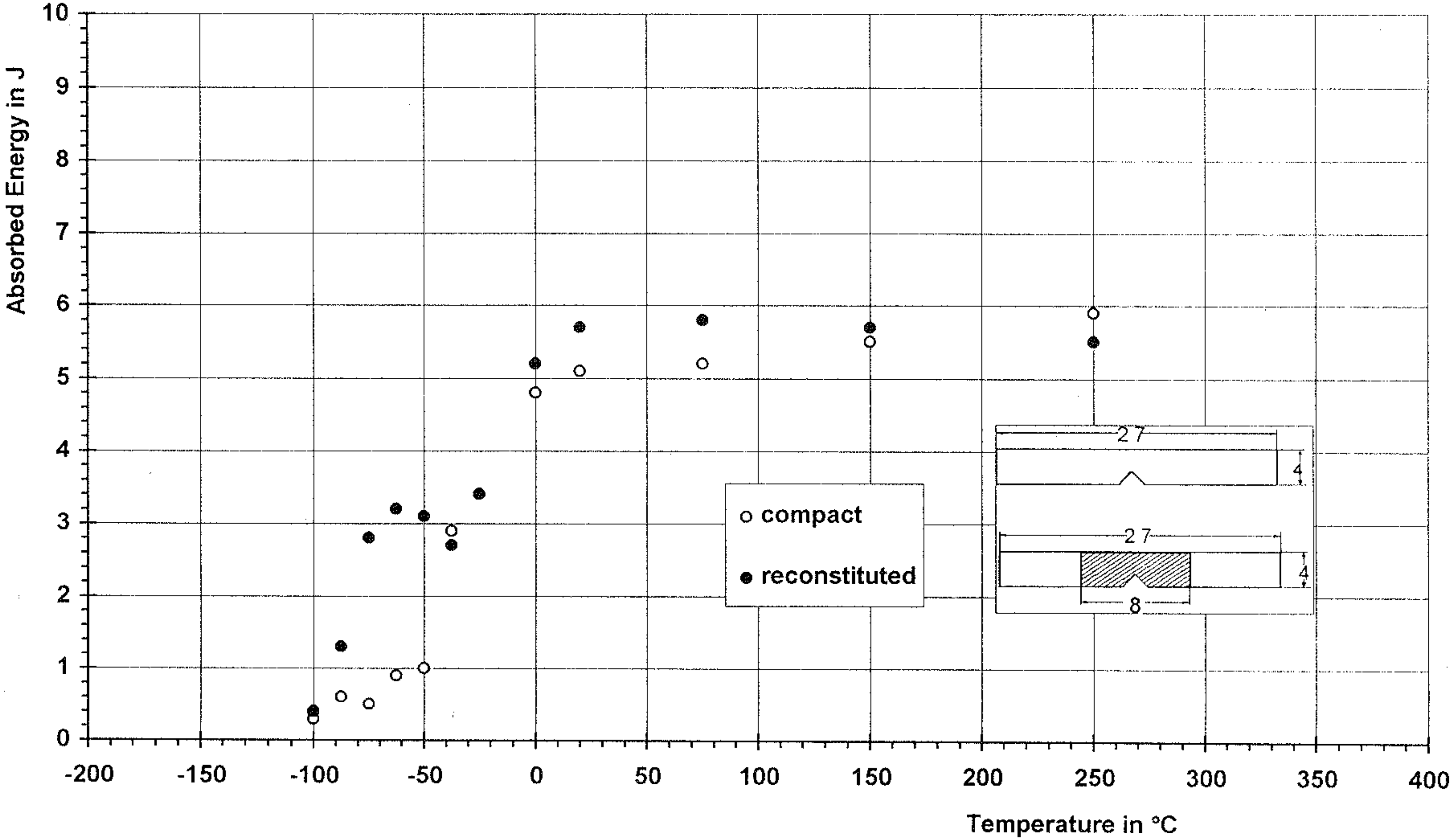
Reconstitution of subsize impact (KLST) specimens from broken Charpy specimens by welding 3 mm x 4 mm cross sections



Comparison of compact and compound subsize impact (KLST) specimens
Weld metal



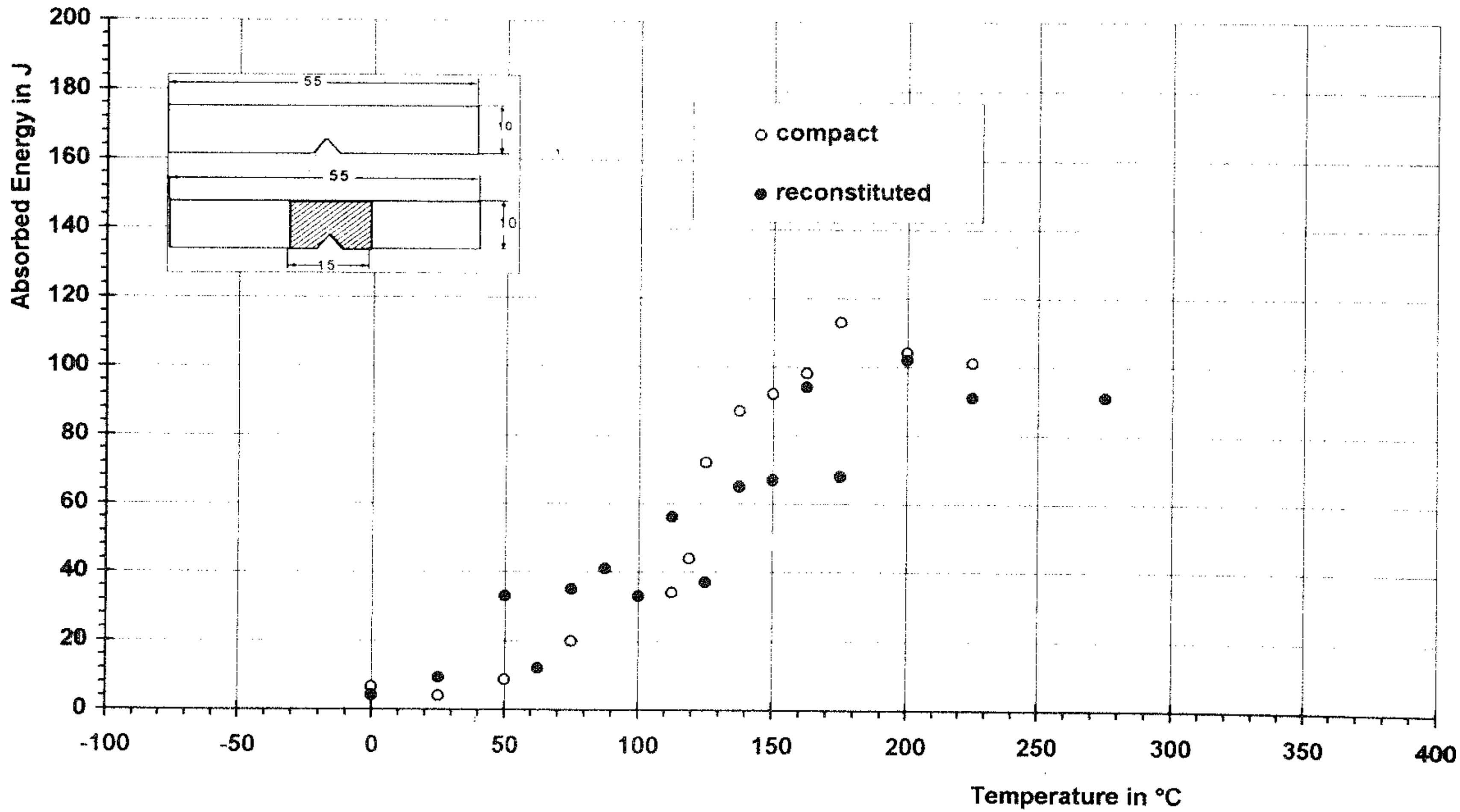
SIEMENS



Charpy Energy of Mini Charpy Specimens, Weld Metal (non-irradiated conditon)

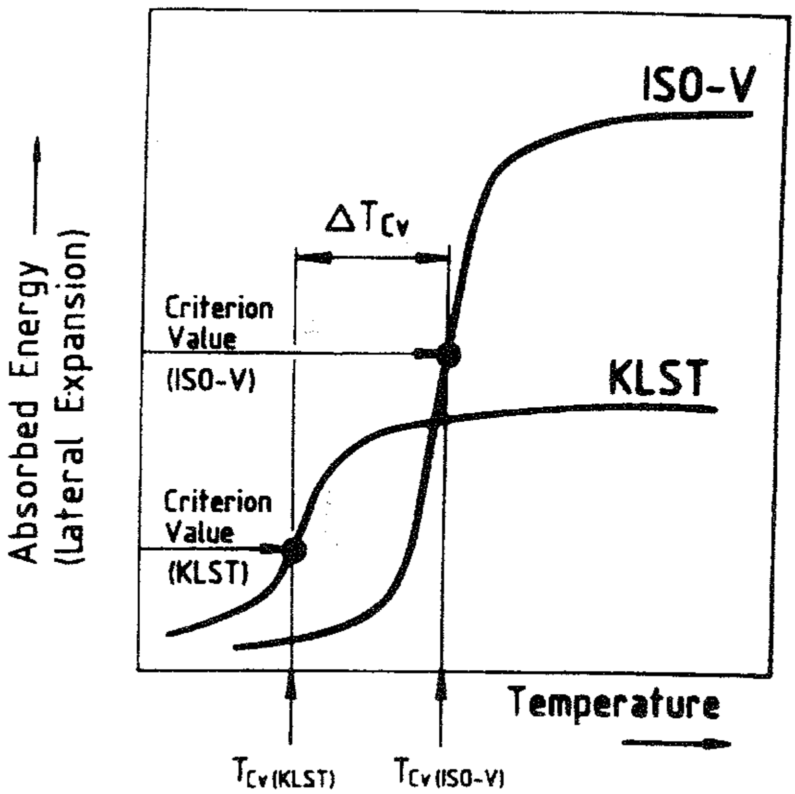
ASME2.XLS/19.12.1996
NT13/Keim E.
Ki-01-4

SIEMENS



Charpy Energy of Normal Size Specimens, Weld Metal (irradiated conditon)

Schematic representation of energy - temperature - curves of Charpy (ISO-V) and subsize impact (KLST) specimens



Correlating criteria	Absorbed energy		Lateral expansion
ISO-V specimen KLST specimen	41 J 1.9 J	68 J 3.1 J	0.9 mm 0.3 mm

Correlation between Charpy and subsize impact (KLST) specimens