PREPARATION OF C-SHAPED SAMPLES OUT OF IRRADIATED CANDU PRESSURE TUBE FOR MECHANICAL TESTS USING THE NUMERICAL CONTROLLED MILLING MACHINE

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ABSTRACT

This milling machine has a cutting feed rate of 0 ÷ 5000 mm/min, an automatic (pneumatic) tool changer for six tools, simultaneous XYZ axis control, and a positioning precision of 0.001 mm.
This machine is installed into a heavy concrete hot cell and is used to prepare C-shape irradiated CANDU pressure tube samples for threshold stress intensity factor (K_{IH}) and delayed hydride cracking (DHC) velocity mechanical tests.

1. Introduction

The milling machine has been used to prepare C-shape irradiated CANDU pressure tube samples for mechanical testing.
The C-shape sample must have a notch for an initiation of delayed hydride cracking (DHC) along the radial direction; this notch plays a key role in the determination of the threshold stress intensity factor (K_{IH}).
To perform the C-shape CANDU pressure tube sample machining, some devices were manufactured: the device to fasten the pressure tube during machining, the device to fasten the sample during cutting its both ends and the device to fasten the sample during notch machining.
The pressure tube is fastened to the milling machine table, the ensemble of both being allowed to move in the XY plane, whereas the milling tool is moving independently along the Z axis. The programming of sample machining needs the size measurement of the pressure tube and needs also the movement coordinates of the milling machine table. A Point Finder is used for size measurements of the pressure tube and a similar tool, fixed on the milling table, is used for dimensional measurements of the milling tools that will be used.
The C-shape sample machining needs six operations for which six different tools are used. All tools are mounted on the tool changer prior to begin the machining and are changed automatically as needed.

2. DM 1007 Numerically Controlled Milling Machine

The 4M CNC control consists of two basic function groups. They are MENU and MONIT. Selection between the two groups can be toggled by pressing the MENU/MONIT key on the upper right corner of the controller panel or by highlighting the MENU or MONIT button on the lower right corner of the screen and pressing INPUT. [1]
The monitor function is used for machine operation and status monitoring. It includes a display of the Machine position (MACHINE), a cutting path display (PATH), Reference position coordinates (POSITION), 3D solid model rendering (SOLID), and teach-in (TEACH-IN) functions (figure 2.1).
The Numerically Controlled Milling Machine is presented in the figure 2.2.

Fig. 2.1 Machine Coordination Display

Basic parameters of the milling machine:

- X, Y, Z axis travel: 250 x 175 x 250 mm;
- Table size: 450 x 180 mm;
- Maximum table load: 60 kg;
- Maximum X, Y, Z axis travel speed: 5 m/min.;
- Cutting feed rate: 0 ÷ 5000 mm/min.;
- Spindle rotate speed: 60 ÷ 8000 rpm;
- Spindle nose to table distance: 95 ÷ 350 mm;
- Spindle taper: BT-30;
- Automatic tool changer;
- Number of tools: 6;
- Tool holder: tip BT-30;
- Maximal tool diameter: 50 mm;
- Maximal tool length: 150 mm;
- Simultaneous X, Y, Z axis control;
- Positioning precision: 0.001 mm;

Software SurfCAM 3 Axis SE. [2]

Fig. 2.2 DM 1007 Numerically Controlled Milling Machine

The hardware structure is presented in figure 2.3.

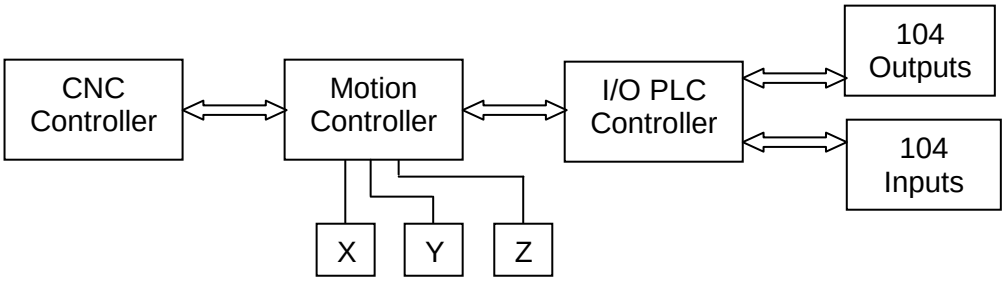


Fig. 2.3 Hardware structure of the DM 1007

The devices used to obtain C-shaped samples out of the irradiated CANDU pressure tube sample are shown in figure 2.4.

Fig. 2.4 DM 1007 Numerically Controlled Milling Machine – Overview of the working table with all devices installed

3. C-shaped sample preparation sequences

To achieve C-shaped sample used these cutting tools:

- Mill no. 1 – (Ø12 Face mill);
- Drill no. 1 – (Ø1.5 Drill);
- Mill no. 2 – (3 x Ø50 Disk mill);
- Mill no. 3 – (Ø6 End mill).

The C-shaped sample is manufactured following the next steps:

- The lenghts of all the milling tools (Mill no. 1, Drill no. 1, Mill no. 2, Mill no. 3) are measured using the “Device for measuring tools”. The length of the “Point finder” is also measured;
- The pressure tube fragment is mounted vertically, into the “Fastening device no.1”, by tightening the fastening screw;
- The height and the thickness of the pressure tube are measured using the “Point finder”. The radius and the coordinates of the center of the tube are then calculated;
- The upper surface of the pressure tube is milled in a horizontal plane, using the “Mill no.1” until a plane surface is obtained. The planarity of this surface has to be good enough so that the sampling of the C-shaped sample is possible;
- The “Drill no. 1” is then used for making the two fastening holes, at the two opposite ends of the sample;
- In order to obtain the lower surface of the sample, a milling of the tube in a horizontal plane is done, using the “Mill no. 2”;

- Prior to cut the ends of the sample, this is fastened using the “Fastening clamp”, by tightening the fastening screw nut;
- The ends of the sample are made by milling the sample in a vertical plane using the “Mill no. 3”;
- The length of the sample obtained in this way is measured using the “Point finder”;
- The C-shaped sample is released out of the “Fastening clamp” by unscrewing the fastening screw nut. [3]

The active areas of the mills are specified by measuring the necessary coordinates, using the measuring tool device TS-27R (figure 3.3, 3.4, 3.5, 3.6).

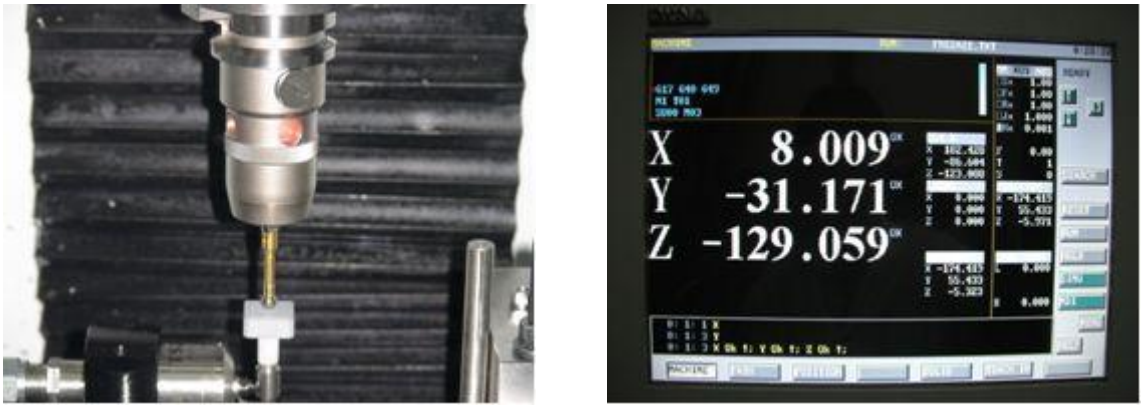


Fig. 3.1 Point Finder measurement using the TS27R instrument

Fig. 3.2 Pressure tube measurement using the Point Finder

Fig. 3.3 Mill no. 1 measurement using the TS27R instrument

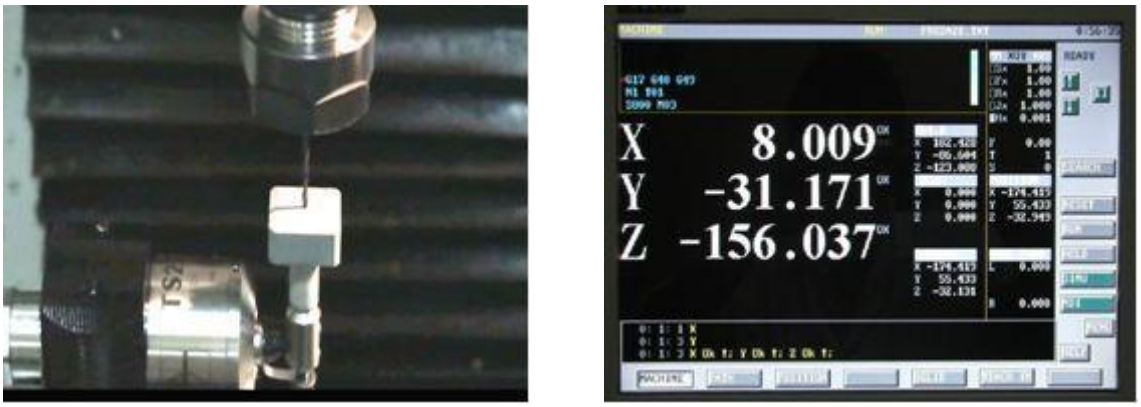


Fig. 3.4 Drill no. 1 measurement using the TS27R instrument

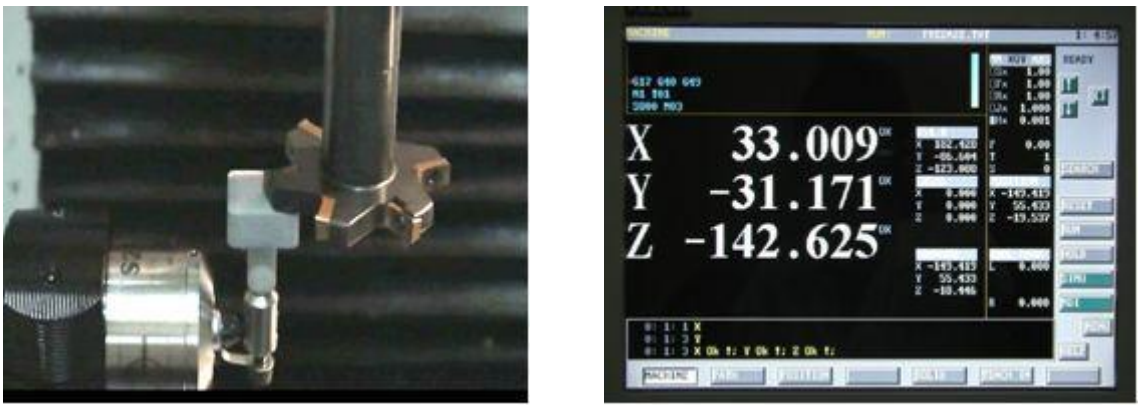


Fig. 3.5 Mill no. 2 measurement using the TS27R instrument

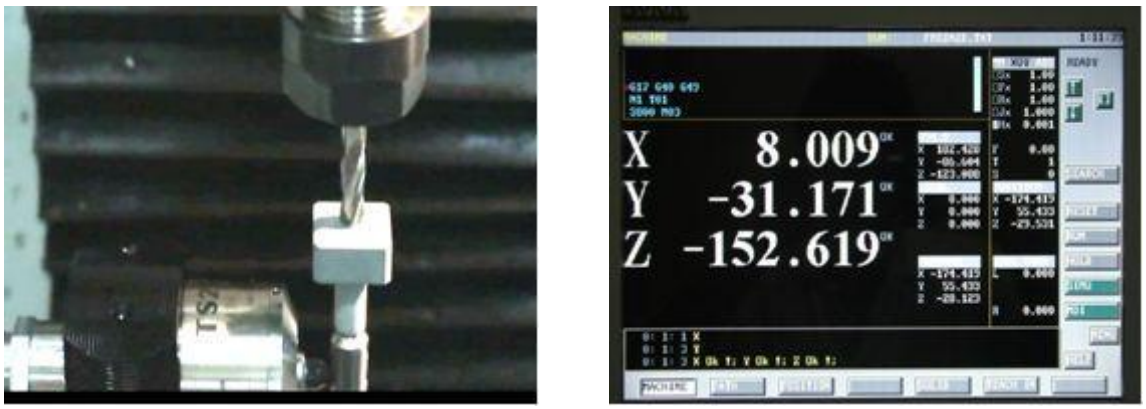


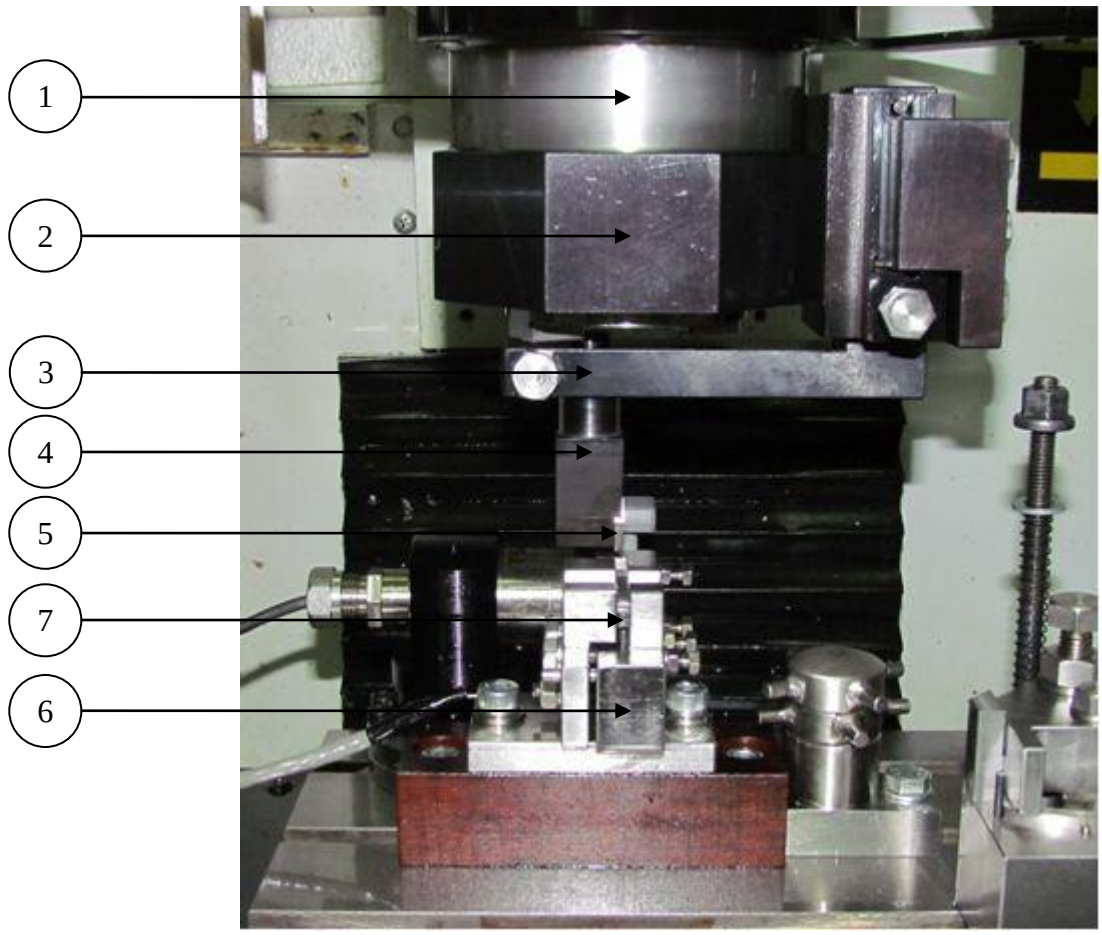
Fig. 3.6 Mill no. 3 measurement using the TS27R instrument

4. V-notch preparation sequences

The V-notch machining was performed by broaching.
The milling machine was modified to perform broaching operation.
Broaching is the machining process by splintering in which the main motion is rectilinear, carried horizontally. The main motion is made by the machine table and the cutting tools perform the advance movement. In figure 4.1 are presented the components used for manufacturing the central V-notch.

The V-notch is manufactured following the next steps:

- Fixed the C-shaped sample horizontally in the “Fastening device no. 2” by tightening the fastening screws;
- The thickness of the C-shaped sample obtained is measured using the “Point finder”;
- The upper surface height and the length of the C-shaped sample are measured using the “Point finder”;
- Fixed the “Cutting tool fixture” in the “CNC head fixture” by tightening the fastening screws;
- The length of the “Cutting tool fixture” is measured using the “Device for measuring tools”;
- The broaching of the V-notch is performed in two stages: first stage is roughing stage and final stage is finishing stage;
- The C-shaped sample is released out of the “Fastening device no. 2” by unscrewing the fastening screws. [3]



1 – CNC head
2 – CNC head fixture
3 – Cutting tool fixture
4 – Cutting tool
5 – Special carbide insert
6 – Support of the C-shaped sample
7 – C-shaped sample

Fig. 4.1 Broaching system for execution of the central V-notch

In order to manufacture the V-notch, the cutting tool “Special carbide insert” was made out of the “carbide insert”, following a sharpening operation (figure 4.2).

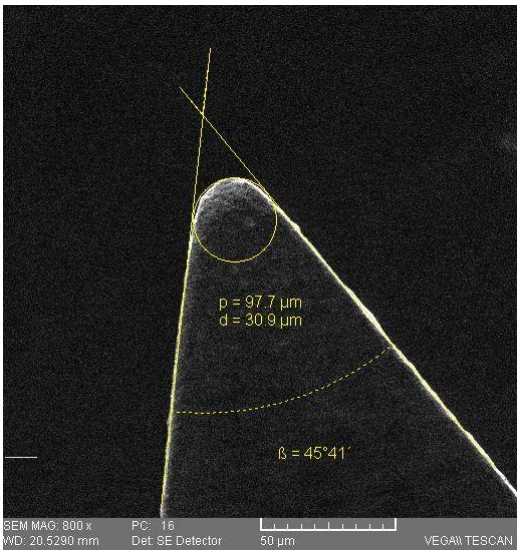


Fig. 4.2 Special carbide insert dimensions: flank angle = 45°41', radius = 15.45 µm

The special carbide insert was measured before using it and after making the V-notch. By this measurement, done using an electronic microscope, the angle and the radius at its tip were determined, in order to assess the wear of the carbide insert.
Once the V-notch was obtained on the surface of the C-shaped sample, its angle, depth and radius at the tip are checked. (figure 4.3) [3]

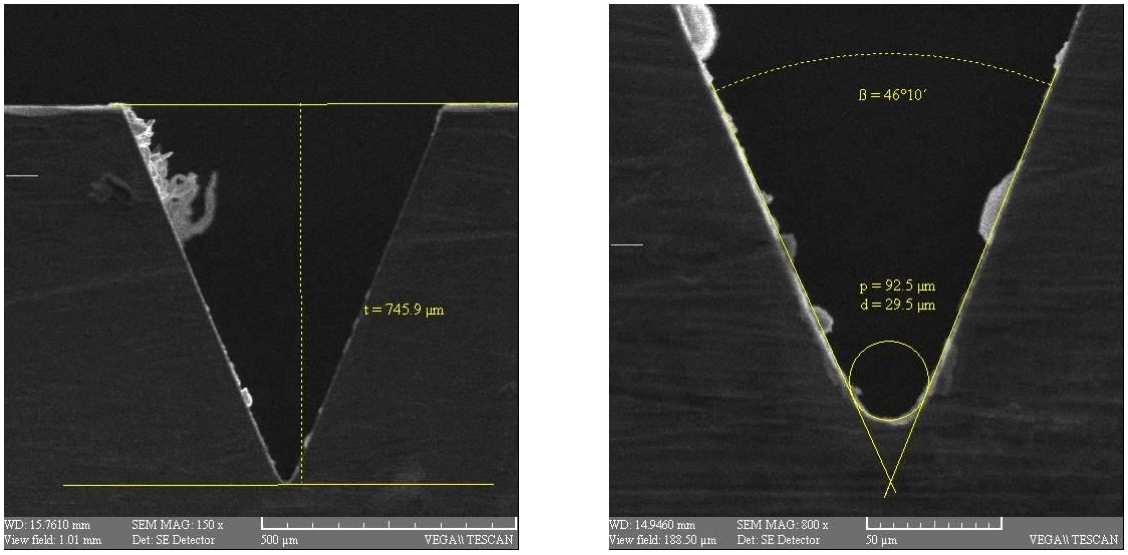


Fig. 4.3 V-Notch dimensions: flank angle = 46°10', depth = 746 µm, radius = 14.75 µm

5. Results

A C-shaped sample is prepared by mechanical procedures, out of a CANDU pressure tube (figure 5.1) and after that is measured as depicted in figure 5.2.

Taking into account the recommendations of ASTM 399, the pressure tube dimensions and the specific work conditions we obtained a sample with the following dimensions:

- crack depth: 0.75 mm;
- material thickness: 4.1 mm;
- material width: 3.3 mm;
- distance between loading axis and fissured surface: 1 mm;

- angle between the crack flanks: 45^{o};
- the radius at the tip of the crack: 0.015 mm;
- total length: 38 mm;
- diameter of the mounting holes: 1.5 mm;
- distance between mounting holes: 33 mm. [4]

Fig. 5.1 C-shaped sample out of irradiated CANDU pressure tub for KIH mechanical test

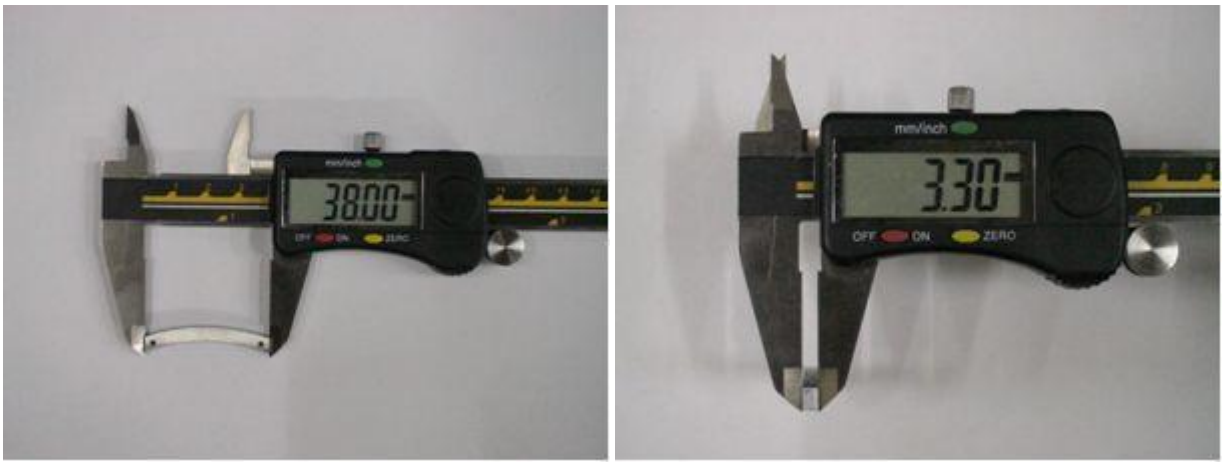


Fig. 5.2 C-shaped sample measurement after machining

6. Conclusions

The C-shaped samples were obtained out of irradiated CANDU pressure tube (made out of Zirconium-Niobium 2.5 %). For this purpose, tools and cutting conditions fitted to the Zirconium-Niobium 2.5 % alloy, precision tools for dimensional measurements (“Device for measuring tools”, “Point finder”), dedicated fastening devices (“Fastening device no.1”, “Fastening device no.2”, “Fastening clamp”) were used. The C-shaped samples manufactured in this way correspond to the technical requirements of the ASTM 399 standard.
This sample is used for the measurement of the mechanical parameters responsible for the initiation and propagation of delayed hydride cracking phenomenon in the radial direction of the irradiated CANDU pressure tubes.

7. References

[1] Dyna 4M – Machine control & Programming Manual
[2] DM1007, EM3116(A) & DM2800 Operation & Reference manual;
[3] EO-TH-94L “Working authorization emitting” INR Procedure;
[4] American Society for Testing and Materials – ASTM 399.