Matrix design for guided bend tests under the codes AWS D1.1, AWS D1.5, ASME Section IX and standard NTC 523 for specimens with thicknesses equal to or less than 3/8 inches

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Abstract. This article presents the design of a guided bending system, which allows integrating the AWS D1.1, AWS D1.5, ASME Section IX and NTC 523 codes. The study meets the requirements of these standards and reduces use of different matrices for testing specimens with thicknesses equal to or less than 3/8 of an inch.

1. Introduction

The industry needs to obtain certifications for its processes and products that guarantee high competitiveness in current markets, it implies complying with international standards related to production, administration, quality policies, the environment, among others. In this context, the metalworking, hydrocarbon and construction industries require quality evaluation of welded joints for their different processes. The guided bend test is a method that is required to qualify the suitability of personnel and welding procedures before carrying out the work [1].

The codes AWS D1.1, AWS D1.5, ASME Section IX and the NTC 523 standard, establish requirements in the shape and dimensions of the matrix to perform this test [2-5]; Each type of specimen requires a different matrix to evaluate the same property, increasing the costs of acquisition, storage and handling of these tools.

It is proposed to design a system that meets the mechanical conditions that the guided bending test requires. The components must be manufactured with the necessary dimensions to comply with the regulations that govern it and be adaptable to any destructive testing machine.

1.1. Guided bend. The test consists of applying a centered load by means of a plunger that acts on the specimen (where the weld is located), supported by two shoulders of a matrix (Figure 1) until it takes the shape of a "U". The result allows to examine cracks or gaps in the welded joint [6].
Where $l$ is the diameter of the plunger, $T$ is the displacement, $w$ and $t$ are the width and thickness of the specimen respectively, and $F$ is the force applied on the specimen.

2. **Matrix design**

The design of the system that integrates the mentioned codes is shown in figure 2. The description of each component is presented in Table 1.
Table 1. Device components for guided bend tests.

| Item | Components     | Description                                                   |
|------|----------------|---------------------------------------------------------------|
| 1    | Matrix base    | Rectangular section plate as matrix support.                  |
| 2    | Frame          | Structure that serves as shoulder support                     |
| 3    | Pins           | Fixing elements for the shoulders that exchanged according to the code. |
| 4    | Shoulders      | Dispositivos que guían el doblez de la probeta. Varían según la norma. |
| 5    | Shoulder stop  | Devices that guide the bending of the specimen. It varies by code. |
| 6    | Plunger        | System component that applies force to the specimen. It varies by code. |
| 7    | Plunger base   | Rectangular section plate that is assembled to the plunger.   |

In the proposed design it can be seen that the only components that must be changed, depending on the code to be applied, are the shoulders and the plunger; the other components remain constant. Figure 3 shows the dimensions of the matrix frame.

![Figure 3](image)

**Figure 3.** Matrix frame. (a) General view. (b) Top view. (c) Side view.

The AWS code establishes requirements according to three yield strength (YS) ranges and they are the same for D1.1 and D1.5. Figure 4 shows the dimensions of the shoulders according to the AWS code for the intervals: (a, b, c) YS less than 50ksi, (d, e, f) YS between 50ksi and 90ksi, (g, h, i) YS greater than 90ksi, respectively. Shoulder dimensions according to NTC 523 and ASME Code Section IX are shown in figures 5 and 6.
Figure 4. Shoulders. AWS D1.1 and D1.5. (a, b, c) YS less than 50ksi, (d, e, f) YS between 50ksi and 90ksi, (g, h, i) YS greater than 90ksi. (a, d, g) General view. (b, e, h) Top view. (c, f, g) Side view.

Figure 5. Shoulders NTC 523 standard (a) General view. (b) Top view. (c) Side view.

Figure 6. Shoulders ASME SECTION IX code (a) General view. (b) Top view. (c) Side view.

Figure 7 shows plunger designs and dimensions according to requirements. The NTC 523 standard plunger maintains the same dimensions required by the AWS code for YS less than 50 ksi [2].
3. Simulation results

3.1. Tensile strength. The material selected for the design calculations was quenched and tempered AISI SAE 4140 steel, from the family of tool steels, whose combined performance of mechanical strength, resistance to fatigue, toughness and limited corrosion, make it a suitable material for the manufacture of the tooling, for being easy to acquire and low cost [7].

The tensile strength \( S \) in external fibers of a beam of thickness \( 2c \) and moment of inertia \( I \), subject to a moment \( M \) is given by [8],

\[
S = \frac{M \cdot c}{I}
\]

For the case of a beam with a rectangular cross section (figure 1) it follows that,

\[
M = \frac{F \cdot l}{4}; \quad c = \frac{t}{2}; \quad I = \frac{w \cdot t^3}{12}
\]

Therefore, the bending force \( F \) necessary to bring the specimen to the \( YS \) can be estimated by means of Eq. (2) [9],

\[
F = \frac{0.67 \cdot S \cdot w \cdot t^2}{l}
\]

For the specimen to exceed the \( YS \), Eq. (2) is multiplied by two, obtaining the following,

\[
F = \frac{1.33 \cdot S \cdot w \cdot t^2}{l}
\]

The values of the forces according to the parameters of each code are shown in Table 2.
Table 2. YS Forces.

| Code or standard | Specimen width w (mm) | Specimen thickness t (mm) | Plunger diameter l (mm) | Tensile strength S (MPa) | Force F (N) |
|-----------------|-----------------------|--------------------------|------------------------|-------------------------|-------------|
| AWS (<50ksi)    | 38.1                  | 9.52                     | 98.43                  | 420                     | 19596.2     |
| AWS (50-90ksi)  | 38.1                  | 9.52                     | 111.13                 | 723.8                   | 29912.7     |
| AWS (>90ksi)    | 38.1                  | 9.52                     | 123.83                 | 1100                    | 40795.9     |
| NTC 523         | 38.1                  | 9.52                     | 98.43                  | 1100                    | 51323.4     |
| ASME Section IX | 38.1                  | 4.76                     | 69.85                  | 1100                    | 18245.1     |

3.2. Simulation results. The “Simulation” tool from SolidWorks design CAD was used. The Von Mises maximum stress criterion recommended for ductile materials was applied, and the safety factor $FDS$ was calculated for each force value (Table 2). The $FDS$ less than 1 (one) indicates that the material exceeded the $YS$ and it was brought to plastic zone. $FDS$ greater than 1 indicates that the material remained in the elastic zone [8, 10]. Figures 8 and 9 show the $FDS$ of the specimen according to the parameters of Table 2.

![Figure 8](image1.png)

**Figure 8.** $FDS$ Specimen under AWS code. (a) $YS$ less than 50 ksi, (b) $YS$ between 50ksi - 90ksi and (c) $YS$ greater than 90ksi.

![Figure 9](image2.png)

**Figure 9.** $FDS$ Specimen under (a) NTC 523 standard. (b) ASME Section IX code

For the $FDS$ simulation of the matrix frame and shoulders, the AWS code ($YS$ greater than 90ksi) and the NTC 523 standard were applied, which require a greater bending force compared to the other codes. The force used in AWS ($YS$ greater than 90ksi) is 40,759.9 N and in NTC 523 it is 51,323.4 N (Table 2). Figure 10 shows the simulation of the matrix frame and figure 11 of the shoulders, respectively.
Figure 10. FDS matrix frame (a) AWS YS greater than 90ksi. (b) NTC 523

Figure 11. FDS shoulders (a) AWS YS greater than 90ksi. (b) NTC 523.

The lowest FDS values of all the simulations are presented in Table 3. In it it is observed that the FDS values for the matrix frame and shoulders components are above 1, this indicates that the material remains in its elastic zone and does not reach the YS. On the other hand, in the case of the specimens, it is confirmed that the forces applied to them exceed their YS, taking them to the plastic zone.

Table 3. Minimum FDS safety factor.

| Component   | Code or standard       | FDS (min) |
|-------------|------------------------|-----------|
| Specimens   | AWS (YS greater than 90ksi) | 0.59      |
|             | NTC 523                | 0.67      |
|             | ASME Section IX        | 0.81      |
| Matrix frame| AWS (YS greater than 90ksi) | 8.88      |
|             | NTC 523                | 28.47     |
| Shoulders   | AWS (YS greater than 90ksi) | 4.21      |
|             | NTC 523                | 4.93      |
4. Conclusions
It was possible to design a set of interchangeable elements that constitute a matrix to carry out guided bending tests of welded specimens under the AWS D1.1, AWS D1.5, ASME Section IX codes and NTC 523 standard. A design model was established of matrices for bending tests, in which the use of materials and manufacturing processes can be reduced, by not requiring the construction of individual matrices for each one.

The FDS values for the matrix frame and shoulders components do not reach the yield strength and the material remains in the elastic zone. In addition, the specimens exceed the yield strength, and are taken to the plastic zone.

5. References
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