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# Thermal Agitation Study on a 90° Surface of the Radius of Curvation of an Elbow

**Sofiane Maachou**
University Centre of Maghnia

**Djezouli Moulai-Khatir**
Abou Bekr Belkaid University

**Abdeldjalil Benbakhti**
University Centre of Maghnia

**Mohamed Mokhtari**
Ecole Nationale Polytechnique Maurice Audin

**Abstract**: The straight sections of steel pipes are subjected to accumulated loads over the course of their service life, which in most cases are highly damaging. Under ambient temperature conditions, the proposed reinforcement to improve the strength of these structures by thermal agitation in A510AP grade steel bends (used in the manufacture of LPG gas tanks and pipes) under mechanical behavior and different bending moment loads, opening and closing, was studied in this work by FEM, and by using the numerical calculation code ABAQUS as well as the XFEM technique with solid elements as structure, our objective is to evaluate the effect of loading mode, internal pressure level, thermal agitation surface and time of this agitation which is expressed by the graduation exponents of the HAZ in the tubular structure in a steel bend under mixed pressure and moment loading. Numerical damage results are presented in the form of moment-rotation curves. They illustrate the variation in damage as a function of these simultaneously acting effects.

**Keywords:** A510AP steel, HAZ, Thermal agitation, XFEM technique, Crack initiation

## Introduction

The innovative idea in our work is to use the new UMM technique (Benzaama et al., 2023) to graduate the heat-affected zone in our tubular structure, in fact the heat-affected zone gives an additional resistance with a new behavior of the material, each zone in the structure has a certain resistance which is a function of the new properties issued by the heat effect in the structure, this heat-affected zone has two parameters; that of the surface previously selected for thermal agitation, and that also of the time of this thermal agitation (Constant et al. (1992), Pratap-Singh et al. (2018), Shimatsu et al. (2000) and Lawrence-Bragg (1934), which is expressed by the graduation exponent of the HAZ Tomerlin et al. (2023), Rui -Yan et al. (2023) and Shrivastava et al. (2023) in the tubular structure with its own base material.

The finite element method is implemented in the standard Abaqus calculation code (Dassault Systemes, 2014). On the basis of two materials, that of the heat-affected zone and the base material, the material failure parameters are scaled by volume fraction. The maximum principal stress is the strength value of the structure, based on the tensile test of the bar specimens tested, which yielded a value of 499MPa. The damage evolution criterion is the maximum tensile displacement (maximum crack opening of the steel is measured at 0.14 mm).

Damage is continuous in the structure, with crack propagation and subsequent stiffness degradation due to element separation. For this, it is necessary to plan methods for repairing cracks (Maachou et al., 2024).

## Geometry Studied and Properties of the Material Used

The geometry studied is a structure of two straight parts on which our boundary condition is applied, such as the load and the structure's attachment, fastened by welding with a 90° elbow. The elbow element is connected to two straight pipes of length 960 mm (Figure 1). The length is sufficient to ensure that there is no stress interference in the region of the elbow due to loads applied to the ends of the linear parts.

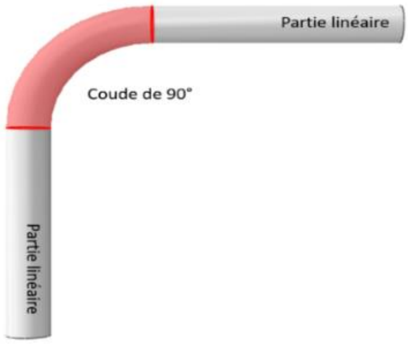


Figure 1. Studied geometry.

Table 1. Mechanical properties of the two zones of A510AP steel (Sliman, 2016)

| Materials | Mechanical properties | |
|---|---|---|
| | Re [MPa] | Rm [MPa] |
| Basic metal (BM) | 297 | 499 |
| Heat-Affected Zone (HAZ) | 480 | 631 |

## Results and Discussion

Our study is based on three levels of graduation that express the thermal agitation time and are applied to the entire surface of the bend; in the upper surface and in the lower surface of the bend.

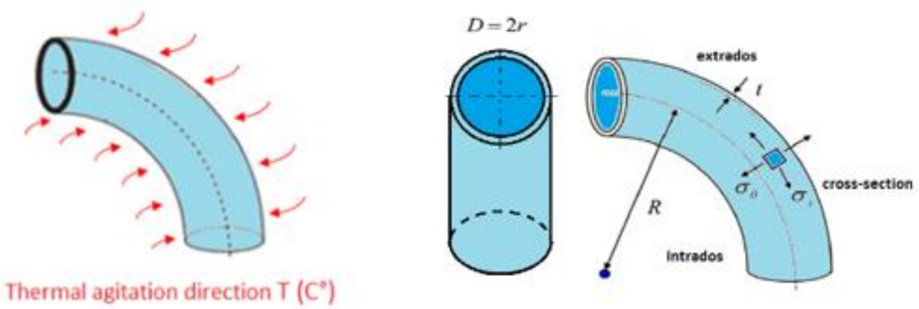


Figure 2. Schematics showing the thermal agitation surface

Fig. 3 and 5 show the structural response to bending mode and pressure damage for 90° surface thermal agitation and different graduation percentages of HAZ in the base material, chosen according to a graduation direction which is usually thickness and with a two-way graduation at the end of the surface thermal agitation. The graduation exponent 0,5 expresses a very low presence, for the graduation exponent 1 is for an identical presence of HAZ in the base metal, and finally 1,5 for a fairly high presence of HAZ in the base metal.

These captures are important to present; we are limited only to the case of the HAZ zone angle at 90° from the surface of the bend. These captures enable us to determine the crack initiation zone, which develops rapidly once it reaches its critical length. We can see that damage starts in the fixed side of the structure, otherwise it is favored at the bend without HAZ reinforcement.

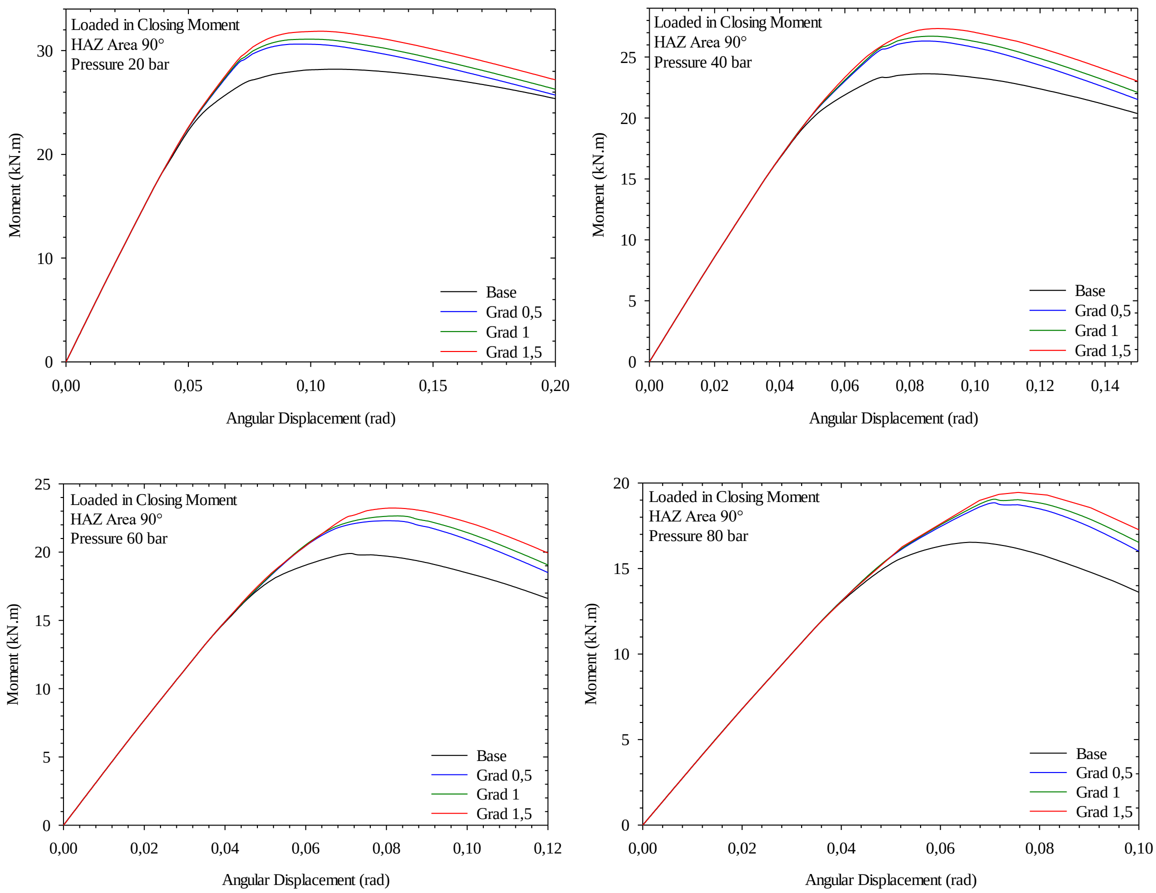


Figure 3. 90° closing graduation effect

In this Fig. 3 we have a bending moment in closure, we studied the effect of the graduation of the HAZ in the base metal at different pressure levels that of 20 bar 40 bar 60 bar and 80 bar, evaluating the response and structural damage helps us to properly identify the behavior under reinforcement of our structure analyze.,

In this bending moment mode (closure), the effect of HAZ scaling is significant, since the thermally affected surface area is large, the pressure effect becomes equally important, always regardless of the thermally-affected surface area, as the internal pressure increases there will always be a decrease in strength, most noticeable in its damage force value. The response of our structure is twofold: elasticity, which is identical due to the graduation effect, and plasticity, which is very different up to the point of damage. Reinforcement in this bending mode is very high, up to 4KNm.

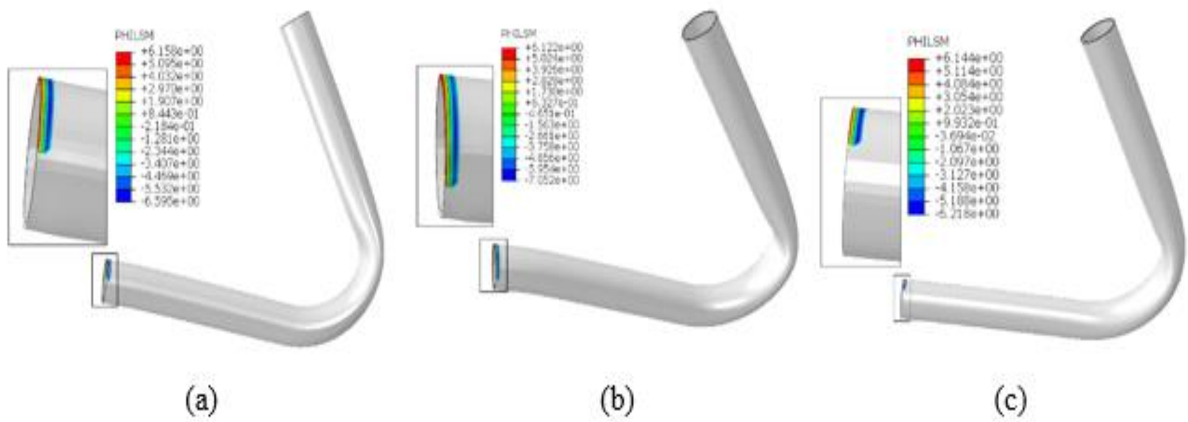


Figure 4. Representation of crack initiation at 80 bar pressure and pure fraction closure bending moment: (a) 1.5; (b) 1; (c) 0.5.

These captures are still the best way of presenting the crack location, but as in the previous presentation, they are limited to the case of the HAZ zone angle at 90° to the surface of the bend. In fact, any damage is rapidly triggered after a very slow crack propagation, but once it reaches its critical length, its propagation speed increases, and its propagation path differs according to the parameters studied in the previous sections. Damage always starts in the fixed side of the structure, otherwise it is favored at the bend without HAZ reinforcement.

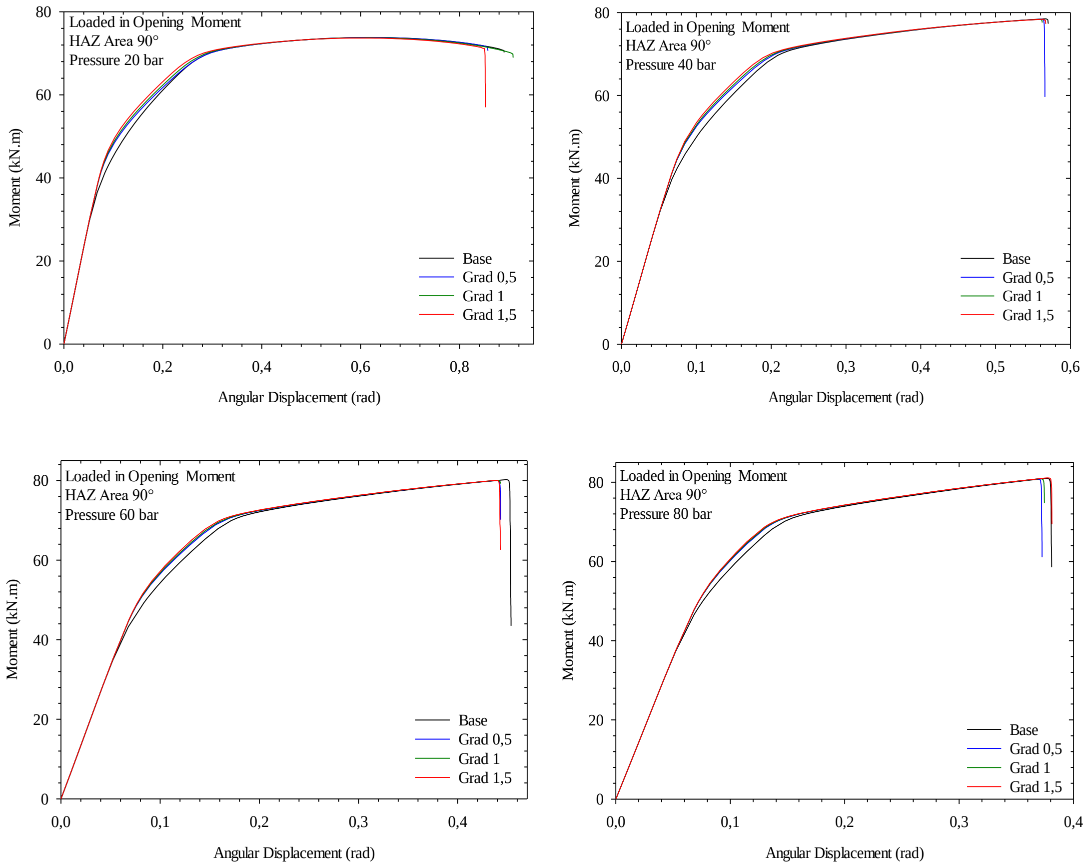


Figure 5. 90° opening graduation effect

In this part of the results presented in Fig. 5, we apply the HAZ graduation over a fairly large area, given by the angle of curvature of the bend, i.e. 90°. As in the previous analysis, we apply this HAZ area to the structure at each internal pressure value, from 20bar 40bar 60bar and 80 bar. In order to gain a broader understanding of the effect of the HAZ.

This figure shows and confirms the same results as above, such as the effect of HAT on the bending moment of the analyzed structure. For different levels of pressure, we still have the same observations: as pressure increases, the opening angle of the bend that corresponds to the damage decreases.

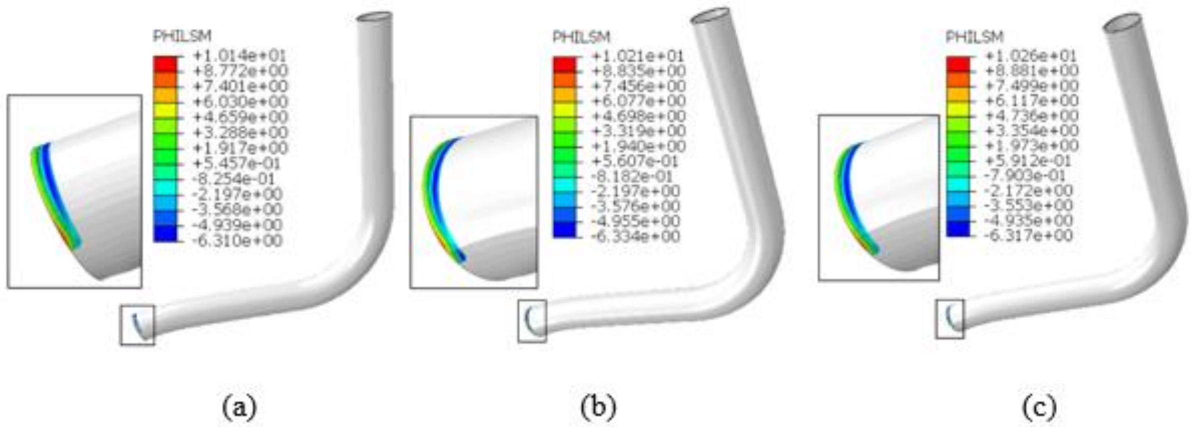


Figure 6. Crack initiation at 80 bar pressure and pure fraction opening bending moment: (a) 1.5; (b) 1; (c) 0.5.

Regardless of the bending mode, the crack location is always the same as that adjacent to the fixed part of our analyzed structure, even when internal pressure is quite high, which is the advantage of these captures. As previously presented, we remain limited to the case of the HAZ zone angle at 90° from the surface of the bend. The bend remains protected by the applied reinforcement of the heat-affected zone.

## Conclusion

A new strengthening technique proposed in this work that can be applicable in tubular structures, these structures that work permanently under internal pressure, to properly present the advantage of our strengthening proposal, it is previously important to make a study on the mechanical behavior and that of the damage of these tubular structures, the conditions of these different structures is in stresses compound accumulated by other loading, our work is the subject of studying our structure with strengthening by surface heat treatment and localize, we have from the results obtained concluded the following:

- Numerical calculation with the new meshing technique eliminates any difficulties in calculation convergence, despite the introduction of several graded damage properties in the same structure, and also despite more complex loading conditions such as the bending moment in the presence of internal pressure and with more complex structure geometries, likewise when it comes to all mechanical behavior up to their damage.
- The XFEM (extend finite element method) technique used in the finite element method to predict damage in a graded structure is a method that proves its advantage in detecting critical values introduced into the graded structure with properties differing from one element to another.
- It can be seen that the closing bending moment is the most dangerous as an accumulated load in the presence of internal pressure.
- We can see that the presence of reinforcement in our analyzed structure considerably increases damage levels.
- In all the cases studied, reinforcement capacity depends largely on the surface area thermally affected and the presence of the HAZ in the structure.
- Using the XFEM method, which has the advantage of presenting the opening, we can locate the damage zone and predict the crack propagation path in the structure.

This numerical approach provides a broad view of mechanical behavior and the possibility of new reinforcement concepts for use in these types of structure to predict damage and improve strength.

## Scientific Ethics Declaration

We, the authors, declare that the scientific, ethical and legal responsibility for this article published in EPSTEM Journal belongs to us.

## Acknowledgements or Notes

* This article was presented as a poster presentation at the International Conference on Technology, Engineering and Science ( www.icontes.net ) held in Antalya/Turkey on November 14-17, 2024.

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## Author Information

**Sofiane Maachou**
University Centre of Maghnia
PB 600, Maghnia, Tlemcen - Algeria
Contact e-mail: *sofianemaachou@gmail.com*

**Djezouli Moulai-Khatir**
Abou Bekr Belkaid University
PB 119, Tlemcen – Algeria

**Abdeldjalil Benbakhti**
University Centre of Maghnia
PB 600, Maghnia, Tlemcen - Algeria

**Mohamed Mokhtari**
Ecole Nationale Polytechnique Maurice Audin
PB 1523, Essenia, Oran - Algeria

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