AISI SAE 1045 steel tenacity variation evaluation subjected to corrosion process by chloride using the Charpy pendulum machine

C G Cárdenas-Arias1,2, A D Rincón-Quintero1,3, C L Sandoval-Rodríguez1,4, B E Tarazona-Romero1,4, J S Muñoz-Gutierrez1, J L Jiménez-Rueda1, O A Acosta-Cárdenas4

1 Design and materials research group (DIMAT), Energy Systems, Automation and Control Research Group (GISEAC), Electromechanical Engineering, Faculty of Natural Sciences and Engineering, Unidades Tecnológicas de Santander (UTS), Bucaramanga, Colombia.
2 Doctoral Program in Engineering of Materials and Sustainable Processes, University of the Basque Country, UPV/EHU, Bilbao, Spain.
3 Doctoral Program in Energy Efficiency and Sustainability in Engineering and Architecture, Department of Machines and Thermal Engines, University of the Basque Country (UPV / EHU), Engineer Torres Quevedo Square, 1, Bilbao, BI, Spain.
4 Doctoral Program in Electronic and Communications, Department of Communications Engineering, University of the Basque Country, UPV/EHU, Bilbao, Spain.

ccardenas@correo.uts.edu.co

Abstract. The steel corrosion affecting study is important for industries and companies as well as for manufacturers of these material types. AISI SAE 1045 steel was used in this study, due to its frequent use. A specimen’s series were prepared which were induced in an aggressive environment with the aim of degenerative process accelerating by increasing the material corrosion impact by altering the material mechanical properties. 15 specimens were exposed to the fog bank chamber, likewise 15 specimens in saline immersion chamber all with different exposure times 15, 30, and 45 days, subsequently the specimens are the impact test subjected to by the method of Charpy obtaining the tenacity value. To determine these values, the ASTM E23, ASTM A673 and ASTM E739 standards were used.

1 Introduction

Steel is considered one of the materials with the highest production worldwide due to its high demand in the different processes and applications within the industry.[1] It is also exposed to corrosion that a degenerative transformation generates directly affecting the material mechanical properties. The corrosion severity and speed will depend on the chemical or electrochemical reactions incidence on the exposed environment, as well as there are variations depending on the type of steel alloy.

AISI SAE 1045 steel it was decided to use to analyze how the corrosion degenerative process affects the material toughness, because it is widely used for the manufacture of automotive parts, the agricultural sector, metal structures, among others; this due to its outstanding characteristics such as hardness and toughness. The study method is experimental[2]: 35 specimens are subjected to saline solutions at different forms and exposure times, formed into groups of 5 test tubes according to the ASTM G-16 standard; the first 5 are the basis of the analysis since these will not be induced to no type of oxidizing agent, for this reason will give us the reference values of study material. 15 specimens will be subjected to an immersion process with sodium hypochlorite as an oxidant with demineralized water, a saline solution to which steel does not offer greater resistance, as they state [3] in their research, for a period of 15, 30 and 45 days respectively. At the same time, another degenerative process of 15 test tubes will be carried out, which will be introduced into a saline mist chamber, using sodium chloride with demineralized water as an oxidizing agent, for a period of 15, 30 and 45 days, they will be extracted in groups of 5 test tubes respectively. Afterwards, the impact tests are carried out on the Charpy pendulum machine, to obtain the quantitative values and verify the AISI SAE 1045 steel toughness variation. This test consists of impacting a specimen located on a support pre-designed for this purpose.
in the machine, by means of a mass that is attached to one end of the pendulum that has a characteristic
distance; it is dropped from a height (h), by means of which the energy of application of the load is
controlled for the subsequent impact. After the test, the information obtained was collected to perform
the calculations and subsequent analysis of the results.

2 Work development

2.1 Design and execution stage.
The ASTM E32 standard was applied to obtain the design parameters required to manufacture the
specimens for the impact tests under the Charpy pendulum.

Figure 1 shows the specimens finished design for the Charpy impact test execution according to
ASTM E-23, taking into account the testing machine type and all the characteristics established for the
test correct development and a result obtaining true.

![Specimen modeling](image1)

**Figure 1** Specimen modeling.

![Machined specimen](image2)

**Figure 2** Machined specimen.

35 specimens are manufactured with the dimensions already specified by the water jet cutting method
in order to make clean and uniform cuts that maintain the characteristics necessary for the test’s correct
development. Finally, they undergo a rectifying process any possible detail or imperfection that they
may have after the previous method, thus obtaining 35 specimens made of AISI SAE 1045 sheet-type
steel with a thickness of ½”.

2.2 Corrosion stage
The exposure time quantification selected for corrosion by the methods of saline immersion and fog
bank, is presented below in the Table 1
### Table 1 Corrosion test type and exposure times

| TEST                        | DESIGNATION | SPECIMEN'S QUANTITY | EXPOSITION TIME (DAYS) |
|-----------------------------|-------------|---------------------|------------------------|
| Saline immersion            | INM-15      | 5                   | 15                     |
| (sodium hypochlorite +      | INM-30      | 5                   | 30                     |
| demineralized water)        | INM-45      | 5                   | 45                     |
| Salt spray chamber          | NIE-15      | 5                   | 15                     |
| (sodium chloride +          | NIE-30      | 5                   | 30                     |
| demineralized water)        | NIE-45      | 5                   | 45                     |

#### 2.2.1 Salt immersion corrosion.
Sodium hypochlorite and demineralized water were used for the corrosion process by the saline immersion method, which were poured into a clean container previously prepared for this purpose[4]. Once the container and the sodium hypochlorite with demineralized water mixture were ready, the test tubes previously marked by groups were introduced, which were left at room temperature and protected to avoid the inclusion of any external agent that could alter the corrosion process.

![Figure 3](image1.png)  
**Figure 3** Saline immersion exposition

According to the schedule to the oxidizing agent exposure, they were extracted in groups of 5 specimens during a period of time comprised in 15 days intervals.

![Figure 4](image2.png)  
**Figure 4** Saline immersion test specimens 15 days
2.2.2  Corrosion in saline fog chamber. For the corrosion test through the cloud chamber, sodium chloride and demineralized water were used, dissolving the substances and pouring them into the storage tank to generate the saline mist, prior to the tank a cleaning process was carried out in order to eliminate external agents that could influence the development of the research as indicated [3] in their research.

The cloud chamber is prepared and the 15 properly marked specimens are introduced, with the objective the corrosion process starting; in order for the three groups of specimens to retain the characteristics necessary for the tests, they are placed at the same height, all this with the purpose that the only variable between them is the exposure time.
The extraction is carried out in groups of 5 specimens during the different time periods defined above of 15, 30 and 45 days respectively.

Figure 8 Test tube positioned in salt spray chamber

Figure 9 Corroded specimens in fog bank 15 days

Figure 10 Corroded specimens in fog bank 30 days
2.2.3 Charpy impact test.

Finished the corrosion process, the Charpy pendulum machine is used based on bibliographic information [5] to obtain the quantitative values of the breakage resistance energy by impact mean (toughness).

The correct operation of the Charpy equipment is checked and the necessary data is taken to perform the toughness calculations of the steel as indicated by the ASTM-E23 standard, the eigenvalues of the Charpy pendulum machine used are presented below:

| Test machine          | Charpy pendulum          |
|-----------------------|--------------------------|
| Arm length            | 0.95 m                   |
| Hammer weight         | 30 kg                    |
| Hammer starting angle | 120°                     |
| Idle hammer end angle | 118.5°                   |

**Table 2** Impact machine features

Figure 11 Corroded specimens in fog bank 45 days
The specimen’s first group test that were without corrosion were carried out, taking the reference to respective data obtained for the subsequent results analysis.

![Figure 12 Charpy pendulum machine](image1)

![Figure 13 Test specimen position](image2)

![Figure 14 Specimens without corrosion after the test](image3)
Figure 15 Corroded specimens for 15 days in fog chamber after impact test execution

Figure 16 Corroded specimens for 30 days in fog chamber after impact test execution

Figure 17 Corroded specimens for 45 days in fog chamber after impact test execution

Figure 18 Corroded specimens for 15 days in saline immersion after impact test execution
Once the impact test execution phase with the Charpy pendulum machine was completed, using the ASTM-E23 standard, the test data of each in the different groups of specimens were collected to perform the necessary calculations to obtain the results and investigation subsequent conclusions.

3 Results
At this research project stage, the necessary calculations were carried out to obtain the results based on the collected data in impact test execution phase on the test pieces different groups, following the ASTM G-16 standard criteria and the analysis was performed by means the different graphs obtained.

Based test without specimen of the Charpy pendulum equipment, the loss due to friction and other factors that the execution of the tests may entail was quantified. The final average angle obtained was 118.5°.

The energy loss is obtained based on the height differential. For this reason, both the initial height with an angle of 120° and the final height with the angle of 118.5° are calculated

\[
\begin{align*}
h &= 0.95 + [0.95 \times \sin(\theta - 90°)] \\
E &= m \times g \times h \\
h &= 0.95 + [0.95 \times \sin(120° - 90°)] \\
h &= 1.425 m \\
Et &= 30 \times 9.81 \times 1.425 \\
Et &= 419.37 J \\
h &= 0.95 + [0.95 \times \sin(118.5° - 90°)] \\
h &= 1.4033 m \\
Ev &= 30 \times 9.81 \times 1.4033 \\
Ev &= 412.99 J \\
E_{\text{loss}} &= E_t - E_v \\
E_{\text{loss}} &= 419.37 - 412.99 \\
E_{\text{loss}} &= 6.38 J
\end{align*}
\]

The lost energy of 6.38 J must be taken into account in tests carried each out to correctly determine the AISI 1045 steel toughness in the different corrosion degrees by the salt immersion and fog chamber methods.
Data obtained in the impact test shows below.

**Figure 21** AISI SAE 1045 steel toughness at different corrosion levels in fog chamber

**Figure 22** AISI SAE 1045 steel toughness at different corrosion levels in immersion salt

| Material exposure times | Corrosion methods |
|-------------------------|-------------------|
|                         | Fog chamber       | Salt immersion |
| Without corrosion       | 90,664 J          | 90,664 J       |
| 15 days                 | 63,424 J          | 62,012 J       |
| 30 days                 | 55,436 J          | 53,564 J       |
| 45 days                 | 38,256 J          | 33,242 J       |

**Table 3** AISI SAE 1045 steel average toughness according to applied corrosion methods and exposure times

With the specimen’s toughness average value that was not any corrosion type subjected, as a reference, it can be seen how this property is affected with time to exposure corrosion as indicated[6].
A toughness reduction of 30%, 38.9% and 57.8% was obtained due to in fog chamber corrosion in the periods of 15, 30 and 45 days, in the same way for saline immersion corrosion at exposure times 15, 30 and 45 days of 31.6%, 40.9% and 63.3% respectively, this being the most critical exposure.

![Graph showing AISI SAE 1045 steel average toughness according to applied corrosion methods and exposure times](image)

Figure 223 AISI SAE 1045 steel average toughness according to applied corrosion methods and exposure times

4 Conclusions
Corrosion affects the AISI 1045 steel toughness an ascending way according to the material’s exposure time to the presents oxidizing agent. for the immersion test case it’s evidenced that at the end of 45 days the material has lost approximately one 63% the ability to absorb energy by impact, which indicator clear of the deterioration level material suffered.

When observing the specimen subjected fracture with 45 days of corrosion, based on the fracture development collected information[7], it can be evidenced that the steel structure has deteriorated presenting a rough surface with signs of that corrosion has penetrated the specimen interior weakening its structure and making it less resistant to impact fractures.

Comparing the corrosion procedures, the immersion is more aggressive, degrading the material at a higher speed, which is observed in the toughness results.

A two-corrosion test representative characteristic used for this investigation is that after 30 days the material exposure, the material’s structure deterioration seems to drastically increase, which has in toughness direct impact.

The longer exposure time, it’s see that, the tenacity difference increases, possibly due to the passivity phenomenon that can occur in a less aggressive environment.

References
[1] C. G. de A. S.A., “SAE 1020 Y SAE 1045,” 2013.
[2] E. A. Pérez Ruiz, A. C. Galeano Perilla, and L. I. Negrín Hernández, “Evaluación de la dureza y microestructura del acero 1045 templado en sustancias refrigerantes no tradicionales,” Sci. Tech., vol. 21, no. 3, p. 213, 2016.
[3] L. Sáenz and E. Patiño, “Impact toughness of the duplex stainless steel SAF 2304, with heating between 1100°C and 1300°C / Tenacidad de impacto de un acero inoxidable dúplex SAF-2304, con calentamientos entre 1100°C y 1300°C,” 2018.
[4] C. G. Cárdenas Arias, A. D. Rincón Quintero, A. Santos Jaimes, and C. L. Sandoval Rodríguez, “Elasticity modulus variation of the AISI SAE 1045 steel subjected to corrosion process by chloride using tension test destructive,” 2020.
[5] E. Medina Bejarano, “Ensayo De Impacto Charpy,” no. October, 2017.
[6] P. Cortes, M. T.; Ortiz, “Corrosion,” Apunt. científicos uniandinos, vol. 4, 2004.
[7] J. Niño, “Propiedades de escalamiento en la fractura de un acero hipoeutectoide,” Universidad Autónoma de Nuevo León, 2003.