Influence of Welding Defects on the Integrity of Pressure Vessels According to ISO 5817

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Abstract: This paper presents a study on the elastic behavior of welded pressure equipment (PE) assemblies, incorporating the weld imperfection quality levels specified in the ISO 5817 standard. The objective is to develop a finite element model of this structure and analyze the maximum stress in fusion-welded plate assemblies. First, welding fundamentals are defined; second, pressure equipment is introduced; third, details of the ISO 5817 standard are outlined. Fourth, welded joints under static loading are modeled using ABAQUS software to determine maximum stresses at their transverse cross-sections. Finally, a comparative study evaluates the performance of quality levels relative to Level B.

Keywords: Welding, Pressure Equipment, Weld Imperfections, Quality Level, ISO 5817, Finite Element Method, Static Loading.

Introduction

P**ressure equipment** (gas cylinders, petrochemical reactors, steam generators, etc.) – ubiquitous in domestic and industrial settings – represent major hazard sources due to the **significant stored energy** they contain. Their failure, whether caused by corrosion, cracking, or operation beyond design specifications, can trigger **catastrophic ruptures** with fragment projection and sudden release of toxic or flammable fluids, leading to devastating human and material consequences. This criticality demands rigorous **structural integrity monitoring**, particularly at welded joints, which constitute critical weak points. Indeed, welding – the essential assembly technique for such equipment – enables geometry adaptation to mechanical and thermal constraints, but the **geometric quality of weld joints** (defined by standards like ISO 5817) is a decisive factor for long-term reliability. However, weld imperfections (cracks, undercuts, misalignments), even when permitted under certain quality levels (B, C, D), can initiate **critical local stress concentrations** under pressure, compromising overall integrity. Therefore, this study uses **finite element simulation (Abaqus)** to comparatively analyze the impact of ISO 5817 quality levels B, C, and D on **maximum stress concentration** in arc-welded joints under identical loading, thereby objectively quantifying their influence on pressure equipment safety.

I. WELDING :

Among assembly techniques, welding holds significant importance across numerous sectors, particularly in all branches of industry and construction. This process optimally adapts structural geometries to service load constraints. Welding is an operation that joins two or more components by establishing material continuity between them – achieved through heating, pressure application, or both – with or without filler metal having a melting temperature comparable to the base material.

Welded joints are categorized according to various weld imperfection types. Crucially, assessing weld joint

Quality level selection relies on a multicriteria analysis encompassing: design specifications, post-weld operations (including cladding), loading regimes (static/dynamic), environmental constraints (thermal, chemical), and failure risk assessment.

II. PRESSURE EQUIPMENTS

Pressure equipment encompasses all devices designed for the production, manufacture, storage, or handling of liquid or gaseous fluids (including steam, compressed, liquefied, or dissolved gases) under pressures exceeding atmospheric levels. This category extends to piping systems for fluid transport in private facilities, along with pressure accessories and safety components. Given their significant stored energy, these systems present major hazards upon failure. They are ubiquitous in domestic settings (e.g., propane cylinders, pressure cookers, air compressor tanks) and industrial environments (petrochemical reactors, distillation columns, storage vessels, sterilization autoclaves). The substantial contained energy can trigger catastrophic rupture due to impacts, corrosion, or operational errors, resulting in fragment projection and sudden release of toxic or flammable substances, causing severe human and material damage. Particularly in chemical/petrochemical sectors, such equipment represents primary risk factors, necessitating rigorous integrity monitoring. Degradation mechanisms include corrosion, cracking in high-stress zones or welds, and operation beyond prescribed pressure/temperature limits. Continued use of compromised units may provoke pressure-induced failure. Consequently, preventive monitoring through targeted inspections is imperative to detect flaws before they become critical. Owners must ensure operational safety via code-compliant inspection and maintenance programs adhering to relevant legislation.

III. ISO 5817 and its content

SO 5817 is a worldwide used Standard for evaluating the weld imperfections. It defines the dimension of typical imperfections which might be expected in normal fabrication. It may be used within a quality system for the production of welded joints. It provides three sets of dimensional values from which a selection can be made for a particular

application. The quality level necessary in each case should be defined by the application standard or the responsible designer in conjunction with the manufacturer, user and/or other parties concerned. ISO 5817 covers the limits for weld imperfections for quality levels as stringent (B), intermediate (C) and moderate (D) (Table 1) [4,5].
The choice of quality level for any application should take account of design considerations, subsequent processing, e.g. surfacing, mode of stressing (e.g. static, dynamic), service conditions (e.g. temperature, environment), and consequences of failure. Economic factors are also important and should include not only the cost of welding but also that of inspection, test and repair [6,7, 8].

Table 1 Quality levels for weld imperfections in ISO 5817

Level symbol	D	C	B
Quality level	Moderate	Intermediate	Stringent

In ISO 5817 the weld imperfections are classified as twenty-six imperfections like cracks, porosity and cavities, solid inclusions, lack of fusion and incomplete penetration, shape imperfections and the multiple imperfections.

IV. Numerical Studies

In this study, the welded joints with the quality levels of the weld imperfections given in ISO 5817 are modeled by using a FEM program, and they are subjected to static loading in order to determine the maximum stresses at the cross-sections of the joints. In the study ABAQUS is used as Finite Element Analysis program [9] .

4-1 Material

The material used in this program is CC20 steel. The thickness of the material is assumed as 10 mm. The property of the material used in the analysis is given in Table 2.

Table 2 Physical and mechanical properties of the material used in the analysis

Properties	**Value**
Elastic modulus	2e+011 N/m^2
Poisson's ratio	0.29
Shear modulus	7.7e+010 N/m^2
Mass density	7900 kg/m^3
Tensile strength	4.2051e+008 N/m^2
Yield strength	3.5157e+008 N/m^2

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4-2 Model and Analysis

In this study, welded joints characterized by different quality levels of imperfections, as specified in ISO 5817, were numerically modeled using the Finite Element Method (FEM) within the Abaqus/Standard environment. The analysis focused on evaluating the mechanical response of butt-welded joints under static loading, with particular attention to the stress concentrations induced by geometric and metallurgical discontinuities. The three-dimensional models were discretized using C3D8R solid elements—eight-node hexahedral bricks with reduced integration and hourglass control—allowing accurate prediction of stress gradients in highly strained regions while maintaining computational efficiency. The results highlight the strong correlation between weld quality level and the magnitude of local stresses, thereby providing quantitative insights into the effect of welding imperfections on the structural integrity and reliability of pressure vessels. This numerical approach helps define more robust acceptance criteria and supports the development of predictive models for fatigue and failure assessment.

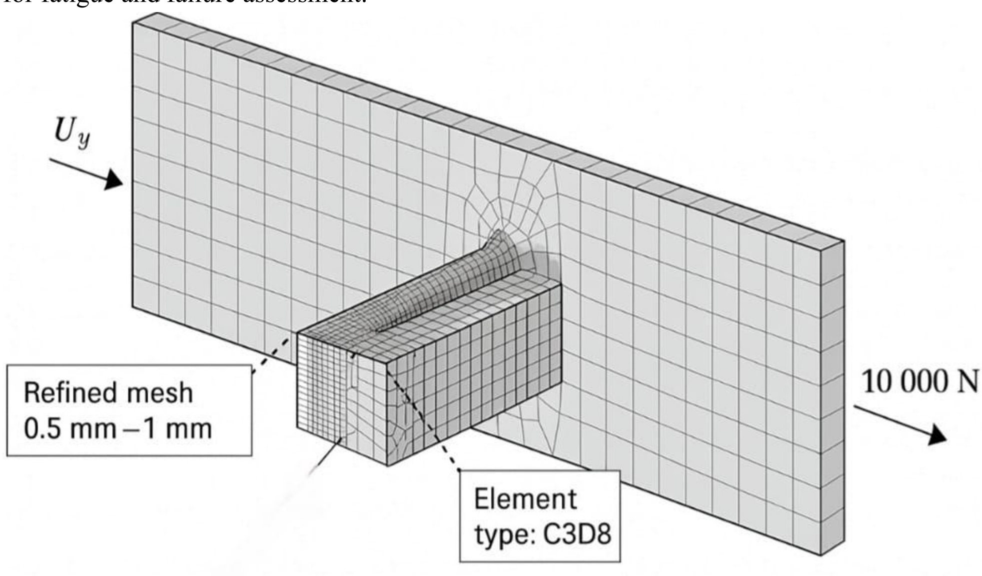

Figure 1 Discretized 3D model of the butt-welded joint used in the finite element simulation

Table3 Numerical Parameters

Category	Desciption
Software	Abaqus/Standard
Method	Finite Element Analysis (FEA)
Joint Type	Butt-welded joint (ISO 5817 levels B, C, D)
Element Type	C3D8R — 8-node hexahedral solid, reduced integration, hourglass control
Mesh Refinement	0.5–1 mm near the weld root and discontinuities
Loading	10 kN uniform tensile load (≈ 10 MPa nominal stress)

Boundary conditions were defined as follows:

- One side of the plate was fully constrained
  $(U_x = U_y = U_z = 0)$
- A total force of 10 kN was applied uniformly on the opposite side, corresponding to a nominal stress of approximately 10 MPa on a 10 mm-thick plate — a realistic load for medium-pressure equipment compliant with ASME VIII.
- The analysis was conducted under static elastic conditions, assuming isotropic linear behavior for carbon steel
  $(E = 2 \times 10^{11}$ Pa, $\nu = 0.29$, $\rho = 7900$ kg/m^3, $\sigma_e = 3.52 \times 10^8$ Pa).

4-3Results

The numerical results show that:

- For butt welds (BW):

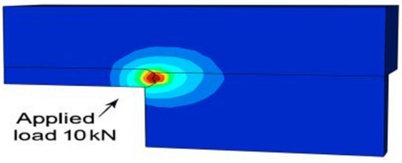

Figure 2 Shows the stress values at the welded joints increase

This figure directly supports the purpose of the study, which is to evaluate the mechanical impact of welding imperfections on the integrity of pressure-vessel components. The model represents a typical welded joint used in pressure equipment, where even small geometric deviations can generate significant local stress concentrations. The color scale—from blue (low stress) to red (high stress)—shows how the stress field evolves according to the quality levels defined by **ISO 5817** (B, C and D). As the weld quality decreases, the high-stress regions (in red) become more pronounced near the weld root and along the fusion line. These critical zones indicate potential sites for crack initiation under service conditions. Hence, the figure demonstrates that lower-quality welds significantly amplify the stress concentration, which directly affects the structural reliability and safety of pressure vessels.

The numerical results show that:

- For fillet weld (FW):

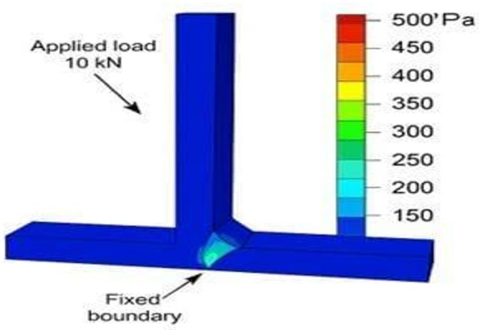

Figure 3 Von Mises stress distribution for a fillet-welded joint under the same loading conditions

This model allows comparison between different weld geometries commonly found in pressure vessels and structural components. The stress contours reveal that, as in the butt-welded joint, the maximum stresses are localized near the weld toe and root regions, where geometric discontinuities intensify the stress concentration. However, due to the angular geometry of the fillet weld, the stress field is more asymmetric, and the concentration zones extend along the weld throat. The color gradient—from blue (low stress) to red (high stress)—confirms that the degradation of weld quality from level B to D (as per **ISO 5817**) significantly amplifies these stress peaks. This behavior demonstrates that fillet welds, although widely used for practical reasons, may exhibit higher sensitivity to imperfections compared to butt welds. Consequently, the figure highlights the need for strict quality control and precise alignment in fillet joints to ensure the mechanical integrity and long-term reliability of pressure equipment.

Table 4 Color scale from blue (low stress) to red (high stress) represents Von Mises stress distribution (0–500 MPa).

Color	Stress Level	Physical Interpretation
Dark Blue	Low (0–100 MPa)	Slightly stressed area, low load
Green	Moderate (150–250 MPa)	Moderately stressed area
Yellow	High (300–350 MPa)	Beginning of the critical zone
Orange	Very High (400–450 MPa)	Highly stressed zone approaching critical level
Red	Maximum (≈ 500 MPa)	Zone of high stress — crack initiation or rupture risk

IV Conclusion

This study investigated the influence of weld imperfections defined in ISO 5817 on the mechanical behavior of welded joints through a detailed numerical simulation using Abaqus. The results clearly demonstrate that the stress distribution within the joint is highly sensitive to the geometric and dimensional characteristics of welding defects.
A consistent trend was observed, showing that the global stress level tends to increase progressively from quality level “B” (stringent) to “D” (permissive), thus confirming the reliability of the ISO 5817 classification in predicting structural performance.
Nevertheless, certain imperfections such as excessive penetration, fillet welds with excessive throat thickness, and excessive asymmetry exhibited a limited effect on stress concentration, suggesting their comparatively lower structural severity.
These findings emphasize the necessity of integrating weld quality assessment into design and inspection procedures for pressure vessels and structural components.
Furthermore, the study confirms the efficiency of the finite element approach as a predictive tool for evaluating weld integrity and identifying critical zones susceptible to failure.
From an industrial perspective, this numerical approach provides a valuable framework for optimizing welding parameters, improving quality control, and ensuring conformity with international standards.
In future work, the research will be extended to include fatigue analysis under cyclic loading, enabling the characterization of crack initiation and propagation mechanisms.
This forthcoming stage aims to establish a comprehensive correlation between the static stress field and the fatigue life of welded structures, contributing to a more robust design methodology and maintenance strategy for critical industrial applications.

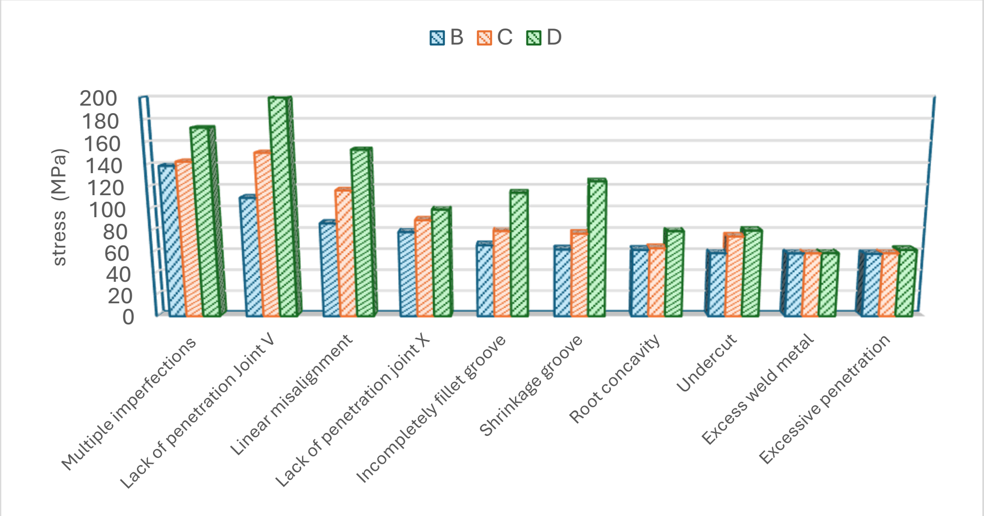

Figure 4 the stress values as a function of different error types and their different quality levels For butt welds (BW)

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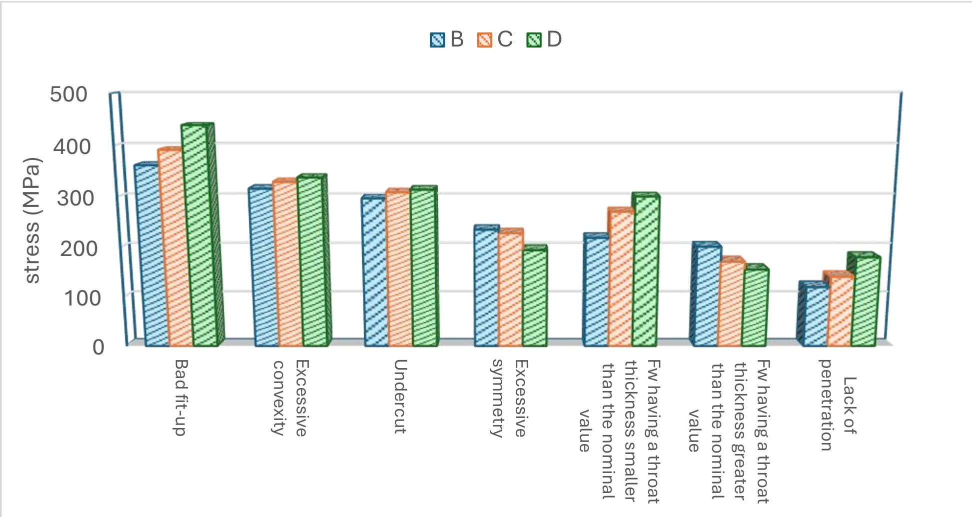

Figure 5the stress values as a function of different error types and their different quality levels For fillet welds(FW)

<table>
<tr><th rowspan="2">Imperfection designation</th><th rowspan="2">ISO 6520 ref.</th><th rowspan="2">Explanation</th><th colspan="3">Limits for imperfections for quality levels</th></tr>
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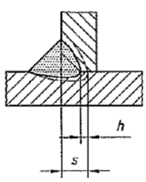
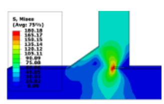
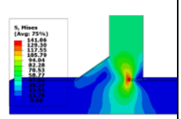
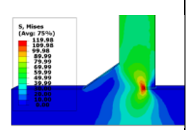
<tr><td rowspan="3">Lack of penetration</td><td rowspan="3">402</td><td></td><td>
66.58%</td><td>
85.09%</td><td>
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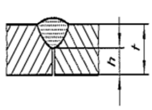
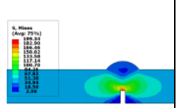
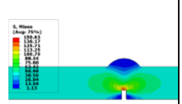
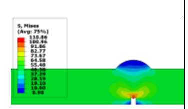
<tr><td></td><td>
55.21%</td><td>
73.06%</td><td>
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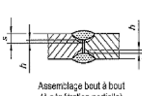
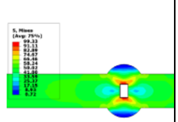
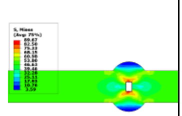
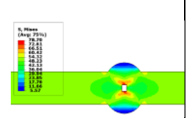
<tr><td></td><td>
79.23%</td><td>
87.76%</td><td>
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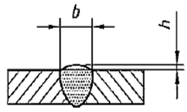
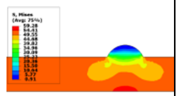
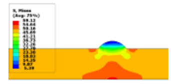
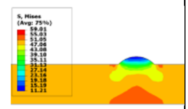
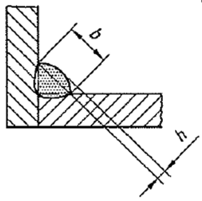
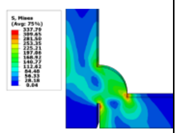
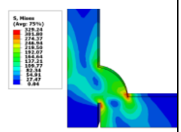
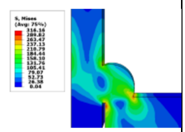
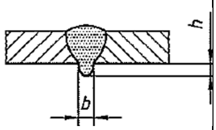
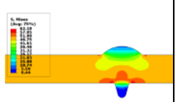
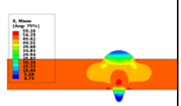
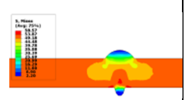
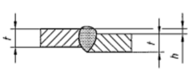
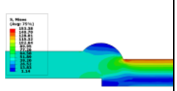
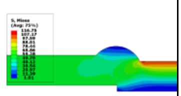
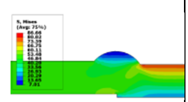
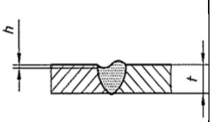
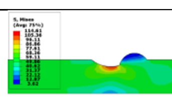
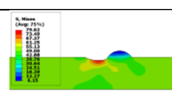
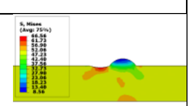
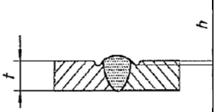
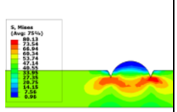
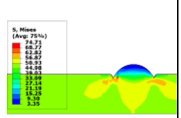
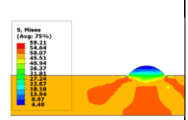
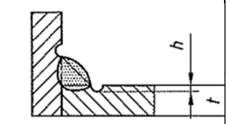
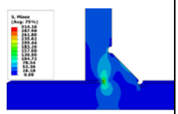
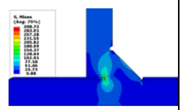
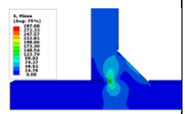
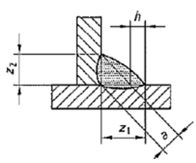
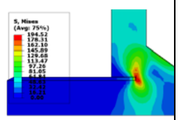
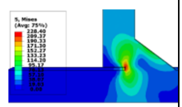
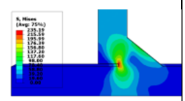
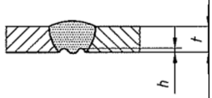
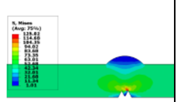
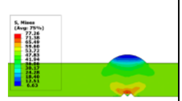
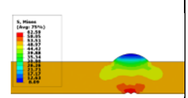
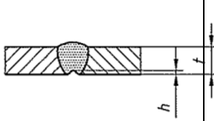
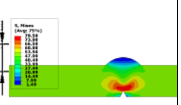
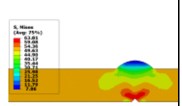
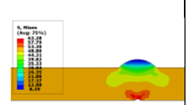
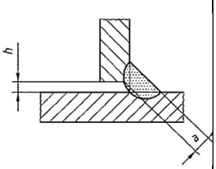
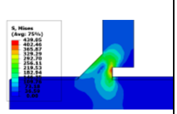
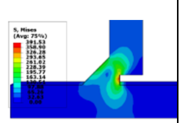
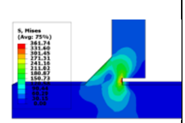
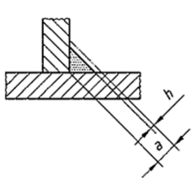
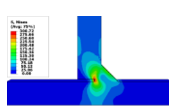
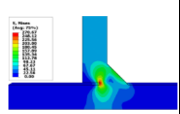
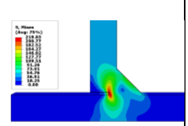
Excess weld Metal	502		 99.54%	 99.81 %	 100%
Excessive Convexity	503		 93.59 %	 96.02 %	 100%
Excessive penetratio n	504		 94.17%	 99.00 %	 100%
Linear misalignm ent	507		 55.77%	 74.13 %	 100%
Incomplet ely fillet groove	509		 58.07%	 83.59 %	 100%
Undercut	501 1		 73.89%	 79.25%	 100%

	5012		 94.56%	 96.20%	 100%
Excessive Symmetry fillet weld	512		 120.90%	 103.97 %	 100%
Shrinkage Groove	513		 50.07 %	 81.01 %	 100%
Root Concavity	515		 78.33 %	 97.60 %	 100%
Filet weld having a throat thickness smaller than the nominal value	617		 82.39 %	 92.39 %	 100%
Bad fit-up, Filet welds	5213		 72.83 %	 80.92 %	 100%

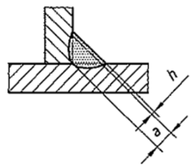
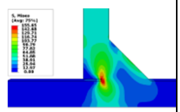
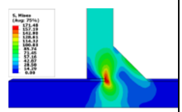
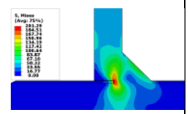
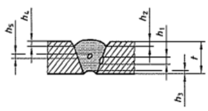
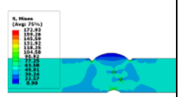
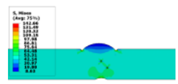
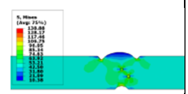
Filet weld having a throat thickness greater than the nominal value	521 4		 129.32 %	 117.38 %	 100%
Multiple Imperfecti on in any cross-section		 $h_1+h_2+h_3+h_4+h_5=\Sigma h$	 80.30 %	 97.35 %	 100%

Figure 6: The performances of the quality levels as compared with those of the level B's as percentages

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[1] ISO 5817: 2007, "*in steel, nickel, titanium and alloys fusion welded (beam welding excluded) Quality -Levels for imperfections*".

[2] ISO 6520, 1982, *"Classification of imperfections in metallic fusion welds, with explanations*".

[7] ISO 4063: 1990, "*Welding, brazing, soldering and braze welding of metals-Nomenclature of processes and reference numbers for symbolic representation on drawings".*

[8] ISO 2553: 1984, *"Weld-Symbolic representation on drawings"*

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[3] M. Vural, "The differences between the strengths of quality levels of weld imperfections given in ISO 5817 », *J. Achiev. Mater. Manuf. Eng., vol. 15*, 2006, no 1- 2.

[4] Carosena Meola, Antonino Squillace, Fabrizio MemolaCapeceMinutolo and Renata Erica Morace, Analysis of stainless steel welded joints: a comparison between destructive and non-destructive techniques *, Journal of Materials Processing Technology, Volumes 155-156, 2004,* Pages 1893-1899.

[5] Jerzy Nowacki and PaweRybicki , The influence of welding heat input on submerged arc welded duplex steel joints imperfections, *Journal of Materials Processing Technology, Volumes 164-165, 15*,2005, Pages 1082-1088

[6] P.K. Palani and N. Murugan Selection of parameters of pulsed current gas metal arc welding, *Journal of Materials Processing Technology, Volume 172, Issue 1*, 2006, Pages 1-10.

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[9] Abaqus, Version 6.11, Dassault *Systemes Simulia Corp. Providence, RI, USA*, (2011).