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The Effect of the Deformations Produced by the Impact upon the Breaking Tenacity of AL-P2014, T42

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Abstract

Whereas the breaking tenacity is influenced by factors related to structural integrity, the authors studied the influence of deformations caused by accidental impact between foreign bodies and a surface of a structure. Tests made for this purpose, aimed to determine the effect of spherical, pyramidal and linear imprint type, applied on CT (ASTM E-399) specimen type, upon the variation of breaking tenacity characteristics of the material, using the critical factor of stress intensity during the state of planar strain.

Key words: *critical factor of stress intensity, hydrostatics intensity, Xu-Wierbicki criterion.*

Introduction

AL-P2014A, T42 alloy is used in both commercial and military fields. Due to its characteristics (good appearance, easy of fabrication, good corrosion resistance, low density and high strength-to-weight ratio, high fracture toughness [5]), this alloy is used, among others, in aviation armor.

Armors can be made in various constructive solutions, a simple classification has to be performed after three criteria [3]:

a. Depending on the role of the armor, they can be:
   - Passive armors;
   - Reactive armor (reactive - explosive BRE or ERA) and slide plates armors.
b. Depending on the manufacturing solution, they can be:
   - Homogeneous armors that can be obtained by casting or lamination;
   - Layered armors (in uniform package, in inhomogeneous package, with sliding plates).
c. Depending on the constructive solution, armors can be classified as:
   - Basic armors or fixed;
   - Removable armors.

The most used metallic materials are special steel alloys for armors and aluminum alloys. The materials for armor must meet certain requirements, which are often contradictory, such as:

- Breaking tenacity to ensure the kinetic energy absorption of the elements that had impacted the armor;
- Hardness to ensure the fragmentation of the projectiles or to prevent the penetration;
- Ductile character in penetration case or rupture, in order to prevent the shrapnel gathering and fragmentation of material.

Characteristics of the Material

In order to obtain valid characteristics for the purpose of the paper, the authors have gathered the material characteristic curve on three specimens taken from AL-P2014, T42 sheet with 1.5 mm thickness (fig. 1).

Fig. 1. Sample of the specimens used for traction test

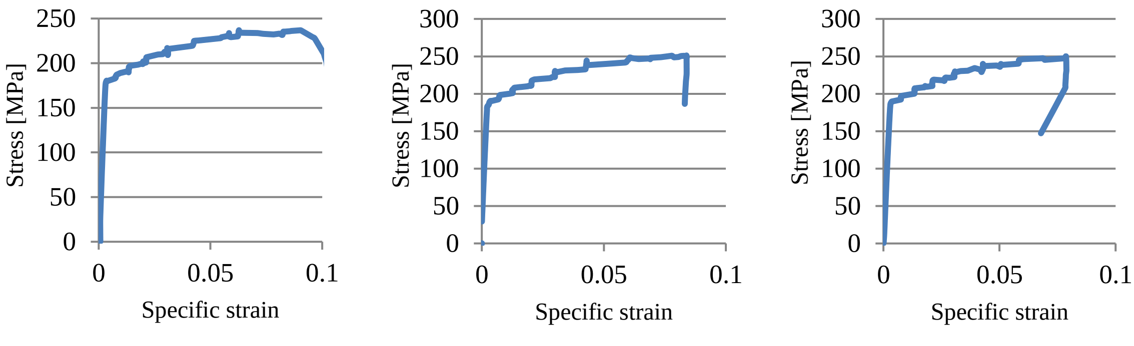
Following tests carried out, there was a deviation in terms of the values obtained, an average thereof was made. The results are presented in Table 1. To the features presented in Romanian standard SR EN 2395 (Table 2), significant deviations are observed. From Figure 1 the breaking mode of the material it can be observed, which presents an area of constriction with a small value before breaking. Figures 2.a-2.c. present the characteristic curves gathered after the tests on the three specimens.

Table 1. Centralization of the characteristic mechanical properties of the tested specimens

Specimen no.	Yield stress [MPa]	Fracture stress [MPa]	Axial extension [%]	Young modulus [$\cdot 10^4$ MPa]
1	177.37	236.99	0.096	56
2	179.16	251.31	0.083	93
3	185.61	249.99	0.077	61
Average value	**180.71**	**246.1**	**0.085**	**70**

Table 2. Chemical composition and mechanical properties of the used aluminum alloy [6]

Aluminium alloy	Chemical composition [max. %]	Thickness [mm]	Yield stress [MPa]	Fracture stress [MPa]	Axial extension [%]
AL-P2014A (T42)	Cr=0,10; Cu=5,00; Fe=0,50; Mg=0,80; Mn=1,20; Ni=0,10; Si=0,90; Ti=0,15; Ti+Zr=0,20; Zn=0,25	0,4-6	240	385	14



a. b. c.

Fig. 2. Characteristic curve of AL-P2014A, T42

Experimental Plan; Apparatus

Specific tests for determining the breaking tenacity (K_{IC}) under plane strain condition, have been developed since this property is directly correlated with the designed material stress and with the estimated dimensions of the defects from structures [2]. Knowing the characteristics of breaking tenacity value, permit to establish a relationship between the amount of stress calculation (σ) and the size of the crack defect (a) [2]:

$$K_{ic} = f\left(\sigma\sqrt{\pi \cdot a}\right) \quad (1)$$

with important indications about the limits of crack inducing (of the defect). This type of testing are among those meant to highlight the characteristics of resistance to crack initiation expansion [1]. The method of determining the breaking tenacity through the critical stress factor in terms of planar strain state, based on the interpretation of force - displacement diagram (Fig. 3), involves calculating the breaking tenacity value using the relationship obtained from elastic solution (2) [4].

$$K_{ic} = \frac{P_Q}{\sqrt{BW}}\left[29.6\left(\frac{a}{W}\right)^{1/2} - 185.5\left(\frac{a}{W}\right)^{3/2} + 655.7\left(\frac{a}{W}\right)^{5/2} - 1017\left(\frac{a}{W}\right)^{7/2} + 638.9\left(\frac{a}{W}\right)^{9/2}\right] \quad (2)$$

where P_Q is the force as determined, B – thickness of the specimen, W – width of the specimen and a – crack length as determined (Fig. 4).

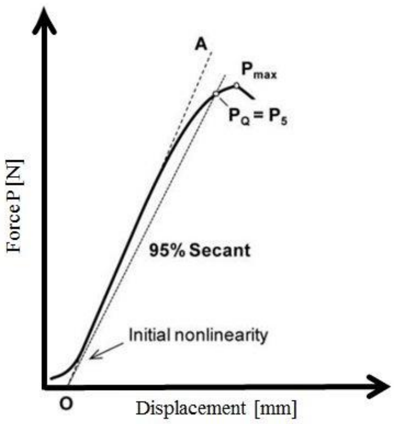


Fig. 3. Force-displacement diagram

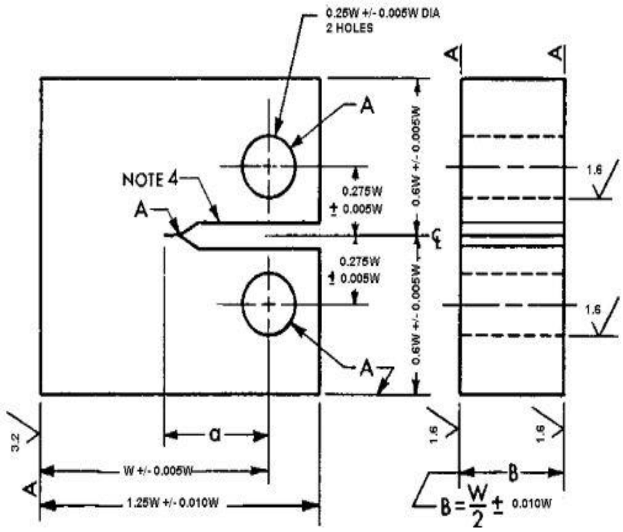


Fig. 4. Standard CT specimen

In order to obtain accurate results, several conditions has to be complained [1]:

- Using forms of specimens according to the standards which are in effect;
- The dimensions of the specimen, especially the transverse one, has to be large enough so that the transverse contraction to the front of the crack to be minimal;
- The acuity of the practiced crack has to be close from the natural one. Therefore specimens are previously subject to varying loads, so a fatigue crack nuclease and spreads on a controlled length of 0.5·W (Fig. 5).

The authors conducted tests to establish breaking tenacity of AL-P2014, T42 after an impact with a foreign material that can deform the body. For this purpose five sets of specimens were created, labeled from P1 to P5. Each set contained standard, with spherical deformation (Fig. 6.a.) with pyramidal deformation (Fig. 6.b.) and linear deformation (Fig. 6.c.) specimens.

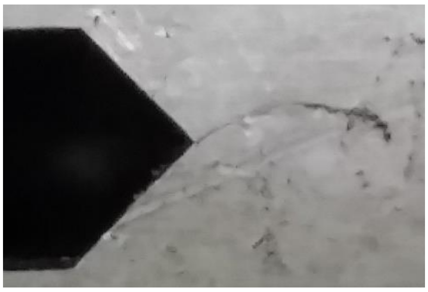
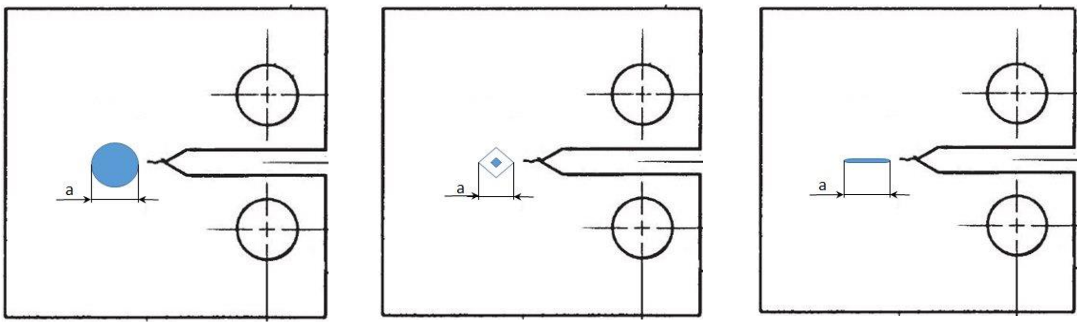


Fig. 5. Fore cracked specimen

For each specimen, the depth of deformation was ranging from 15% of the thickness (B) to 30% of the thickness, with an increment of 5%. To determine the force – displacement curve has been used a TIRA - test2151 equipment made by Heckert company, with force cell, an Epsilon extensometer 3542-050M type with an opening area of 25 mm, specimens being controlled pre cracked through a fatigue testing machine of own manufacturing.



a. b. c.

Fig. 6. Deformed specimens

Results

After tests, it was possible to centralize the data in Table 3.

Table 3. Breaking tenacity values for each type of the used specimen

Sample	K_{IC} [MPa·m$^{1/2}$]			
	Standard specimen	Ball imprint	Pyramid imprint	Longitudinal imprint
P1	42.2	45.6	36.5	38.7
P2	41.8	45.8	36.8	38.5
P3	42.3	45.5	36	38.9
P4	42.1	45.6	35.9	39
P5	41.9	45.4	33.8	37.6

A suggestive evaluation of tests can be obtained from graphical analysis. Thus, in Figure 7 an increase of breaking tenacity of ball imprint specimen is observed, compared to the standard one. At the same time, other specimens have a breaking tenacity under the standard specimen, the largest decrease to the pyramidal imprint one being recorded. It is estimated that in the latter specimens, the imprint generated after the impact between the base material and a foreign object, primed other cracks in the plastic nucleation area. For specimen with longitudinal imprint, the situation is less dangerous than either of the pyramidal imprint, produced by the penetration in the base material of an apex body. The better behavior of specimen deformed by a spherical body that produces a ball imprint can be explained if we take into account the criteria of cracks assessment developed by Xu and Wierbicki and if it is taken into account the Lode's angle also.

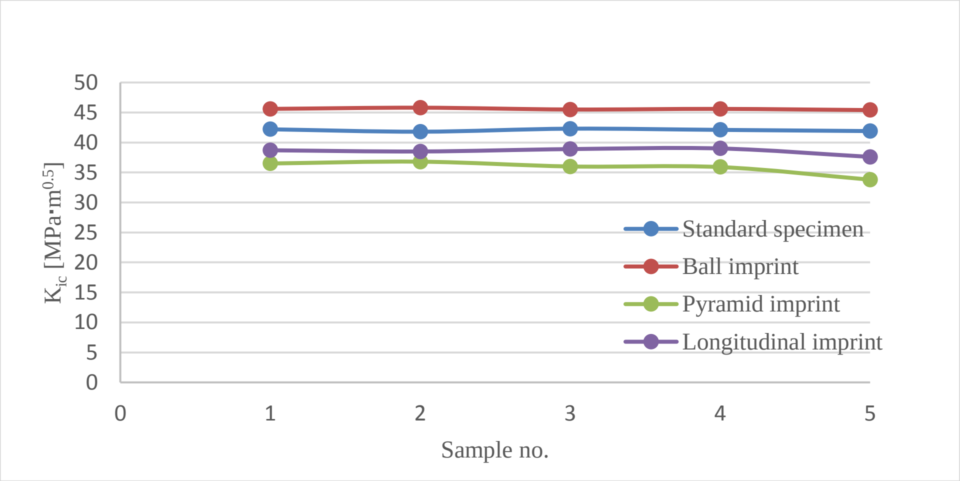


Fig. 7. Breaking tenacity for all samples

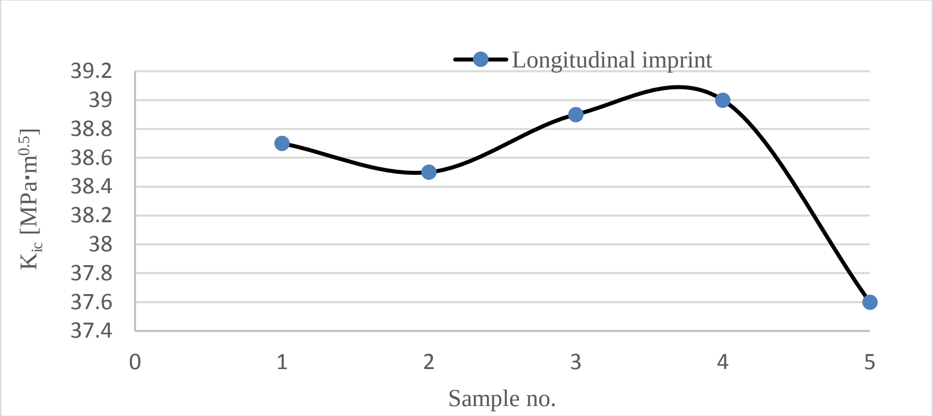


Fig. 8. Breaking tenacity for longitudinal imprint

The importance of the impact size upon breaking tenacity values is highlighted in Figures 8 and 9. In both cases it is observed that a small impact force, breaking tenacity values increases for the ball imprint (Fig. 7) and for the longitudinal and pyramidal imprint it decreases for 1% approx. This process is explained by the hardening of the material.

If the force of the impact increases and implicitly the footprint depth, damages appears in the intimate structure of the material (for longitudinal pyramidal imprint - Figs. 8 and 9) and the breaking tenacity measured values decreases to 10% approx.

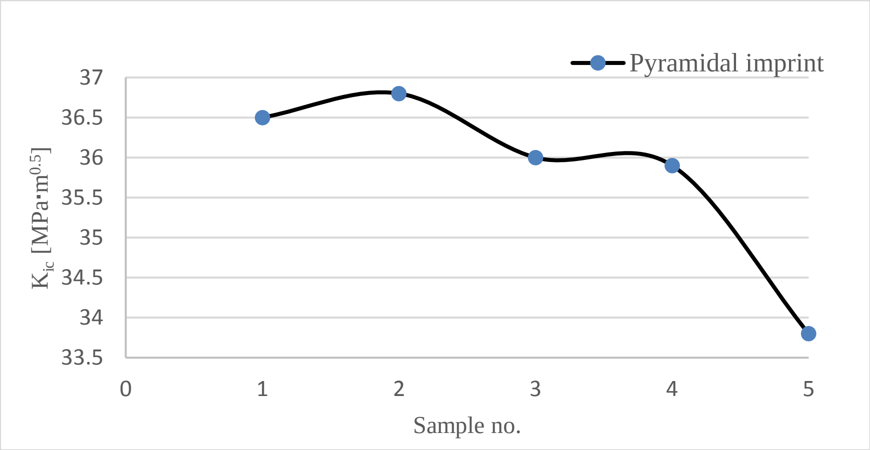


Fig. 9. Breaking tenacity for pyramid imprint

Conclusions

The impact of different bodies to a basic material change its mechanical properties, mainly breaking tenacity. This phenomenon can be explained, for spherical imprint, by a local hardening of the material, for the imprints that destroys the base material microstructure by altering the characteristics of the plastic enclave in the direction of crack propagation. In addition to dedicated methods in fracture mechanics, for the crack growth rate appreciation (K_{IC}, DCVF, J integral etc.) should be considered hydrostatic pressure of the material at the crack nose and the incident angle under which the collision occurs with the foreign body.

The study is important especially for large pipe that belongs to pressurized transport networks, carrying supercritical state agents, pipes that can be stressed through impact by a faulty handling.

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Efectul deformaţiilor produse la impact asupra tenacităţii AL-P2014A, T42

Rezumat

Întrucât tenacitatea este influenţată de factori ce ţin de integritatea structurilor, autorii au studiat influenţa deformaţiilor cauzate de impactul accidental între corpuri străine şi suprafaţa structurii. Determinările efectuate în acest scop, au urmărit efectul deformaţiilor de tip sferic, piramidal şi linear, aplicate epruvetelor de tip CT (ASTME E-399) asupra variaţiei caracteristicilor de tenacitate ale materialului utilizând metoda factorului critic de intensitate al tensiunilor în condiţiile stării plane de deformaţie.