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# Effect of ring notch radius on the decohesion mode in AlSi alloys

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## Abstract

The article discusses the effect of the, determined by tensile test, non-linear characteristics of AlSi alloys on the value of the shape factor k for the three different sizes of the radius of the ring notch made on round specimens. Applying a numerical solution, the changes of stress in the notch plane were determined in function of the notch configuration and the value of instantaneous load. Tensile tests were carried out on round bars with ring notches. The appearance of fractures was examined on scanning images. Differences in notch effect observed in the linear-elastic and elastic-plastic model of material hardening in a non-linear mode were described.

**Keywords:** docohesion, elastic-plastic model, strain, nominal-stress, HMH hypothesis

## 1. Introduction

The places of changes in the cross-section and surface curvature of an object are the source of local high stresses, known as notch effect. This effect is caused by the presence of such design features as holes, transverse and oblong grooves, mounting points, recesses, threads, etc. In a bar made of homogeneous material with linear elastic characteristics, subjected to the effect of tensile forces, the stresses achieve their highest value $\sigma_{max}$ in the bottom part of the notch. When the notch is absent, the nominal stress $\sigma_{nom}$ in the cross-section $A_k$ reduced by the notch cross-section area amounts to:

$$\sigma_{nom} = \frac{P}{A_k} \tag{1}$$

where : P – the axial load exerted on the bar.
A measure of the stress concentration is the, so called, shape factor, also known as a theoretical stress concentration factor $\alpha_k$:

$$\alpha_k = \frac{\sigma_{\max}}{\sigma_{nom}} \tag{2}$$

The notch effect in the stretched bar with a ring notch changes the linear state of stress into a triaxial state. In elastic state, the factor $\alpha_k$ is the quantity related only to the notch geometry; it does not depend on the type of material, the value of load, or dimensions of the tested element.

If, however, an elastic-plastic model is adopted along with the non-linear stress-strain relationship valid for the examined material, the distribution of stresses in the notch plane will naturally change, while the value of the notch factor $\alpha_k$ will depend on both the material type and load level. Attempts were made to allow for the presence of plastic deformation in the notch area while describing the notch effect, e.g. by means of the most often applied Neuber postulate [1]:

$$\alpha_k = \alpha_\sigma \cdot \alpha_\varepsilon = \frac{\sigma_{\max}}{\sigma_{nom}} \cdot \frac{\varepsilon_{\max}}{\varepsilon_{nom}} \tag{3}$$

where : $\varepsilon_{max}$ - the strain in the bottom part of the notch corresponding to the stress $\sigma_{max}$,
$\varepsilon_{nom}$ – the nominal strain corresponding to the stress $\sigma_{nom}$.

The stress distribution within the area of a ring notch made in the tested bar can be predicted from Bridgman solution [2]. The said solution interrelates the degree of triaxiality of the state of stress $T_t$, in the central part of the specimen with the geometry of the specimen in which the ring notch has been made, using for this purpose the following relationship:

$$T_t = \frac{\sigma_m}{\sigma_{\text{int}}} = \frac{1}{3} + \ln\left(1 + \frac{R}{2\rho}\right) \qquad (4)$$

where :

$\sigma_m$ – the mean stress value, which is an arithmetic mean of the normal stress components $\sigma_1$, $\sigma_2$, $\sigma_3$ :

$$\sigma_m = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3} \qquad (5)$$

where:

$\sigma_{\text{int}}$ – the stress intensity determined by Huber–Mises–Hencky hypothesis (the HMH hypothesis) :

$$\sigma_{\text{int}} = \frac{1}{\sqrt{2}}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]^{\frac{1}{2}} \qquad (6)$$

The degree of triaxiality of the state of stress $T_t$ affects the process of ductile fracture of the material, because the spherical component of the stress tensor $\sigma_m$ is interrelated with the process of the initiation and growth of voids [3,4,5]. In this study, a comparison was made between the values of the theoretically computed $T_t$ and the numerically computed degree of triaxiality of the state of stress $T_n$ for the three ring notch geometries.

## 2. Test material and types of specimens used in investigations

The specimens for mechanical tests were made from an AlSi alloy of the following chemical composition:

Table 1 Chemical composition of the tested AlSi alloy

| Element | Al | Si | Cu | Mg | Ti | Zn | Fe |
|---|---|---|---|---|---|---|---|
| Percent content | 89,64 | 8,5 | 1,1 | 0,5 | 0,11 | 0,1 | 0,05 |

Mechanical tests were conducted on plain specimens of 7 mm diameter and on 14 mm diameter specimens with ring notches of the radius amounting to 2 mm, 4 mm and 7 mm (Fig.1). The specimen diameter in the notch plane was constant in each case and amounted to 7 mm.

## 3. The results of experiments and numerical computations

Above 0,3 % strain, the tested AlSi alloy is characterised by a non-linear stress-strain relationship (Fig.2), and therefore, within the notch area, some local non-linear deformations may occur.

Compared with plain specimen, the specimen with a ring notch was characterised by a considerable decrease of the strain value. On the other hand, the value of the force at which the specimen failed has increased (Fig. 3), (Table 2).

The centrally taken scanning image of a fracture formed in the plain specimen shows the regions of plastic deformation (Fig.4d). An indentation made on the ring notch increases the share of brittle fracture, the more the smaller is the radius of this notch (Fig. 4). When the radius ρ is 2mm (Fig. 4a), the fracture has no zones of plastic deformation in its central part any longer. Under the effect of increasing loads, the above mentioned differences in the type of material decohesion bring changes to the stress-strain state within the notch plane, following now a different route due to changes in the ring notch radius. The numerical computations carried out by the finite element method (FEM) on axially symmetrical models of the specimens with 2, 4 and 7 mm notches, to which, basing on the conducted tensile tests, the non-linear material characteristics were ascribed, indicated some discrepancies existing between the conventional linear and non-linear description of the problem.

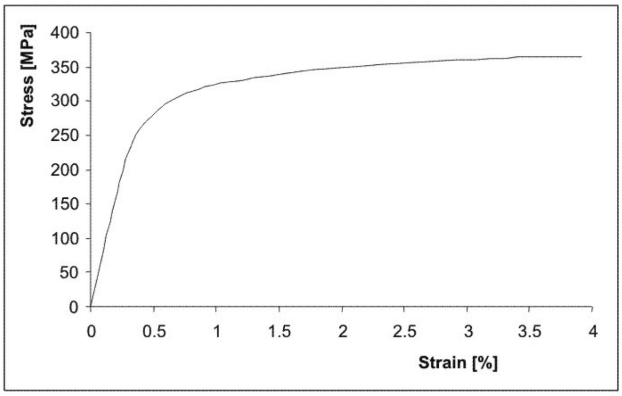

Fig. 2 The tensile curve for plain AlSi alloy specimen.

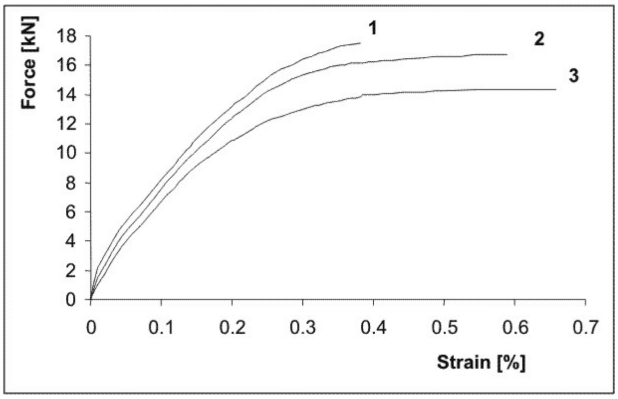

Fig. 3. The tensile curves for the specimens with ring notches of different radii ρ; curve 1- ρ = 2 mm, curve 2 - ρ = 4 mm, curve 3 - ρ = 7 mm

Table 2. Mechanical properties of AlSi alloy vs notch radius

| Notch radius | Tensile force at failure | Strain | Theoretically calculated triaxiality factor | Numerically calculated triaxiality factor | Shape factor |
|---|---|---|---|---|---|
| ρ [mm] | $F_m$ [N] | ε [%] | $T_t$ | $T_n$ | $\alpha_k$ |
| 0 | 14000 | 3,98 | 0,33 | 0,33 | - |
| 2 | 17500 | 0,38 | 0,96 | 1,01 | 1,60 |
| 4 | 16700 | 0,59 | 0,69 | 0,71 | 1,45 |
| 7 | 14400 | 0,66 | 0,55 | 0,58 | 1,10 |

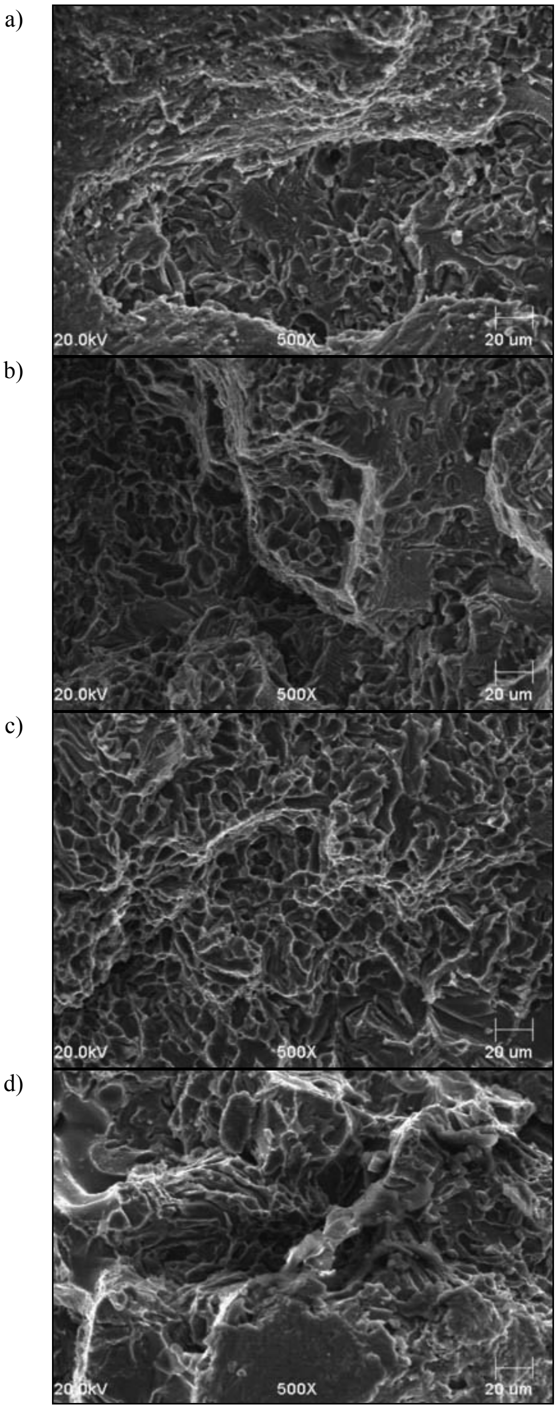

Fig. 4. Photographs of fractures in the AlSi alloy taken near the axis of the specimens with different ring notch radii ρ: a - ρ = 2 mm, b - ρ = 4 mm, c - ρ = 7 mm, d – plain specimen; 500x

When the fracture is of a brittle character (the notch radius ρ = 2 mm), the effort mainly depends on the axial stress component $\sigma_2$, which at the instant of decohesion has the same value in the axis and in the notch (Fig. 5). On the other hand, when the regions of plastic deformation are visible in the fracture, the stress intensity effect $\sigma_{int}$ expressed by the HMH hypothesis is increasing (Fig. 6). On the other hand, with increasing load, the axial stress $\sigma_2$ decreases in the notch area and increases in the specimen axis (Fig. 7).

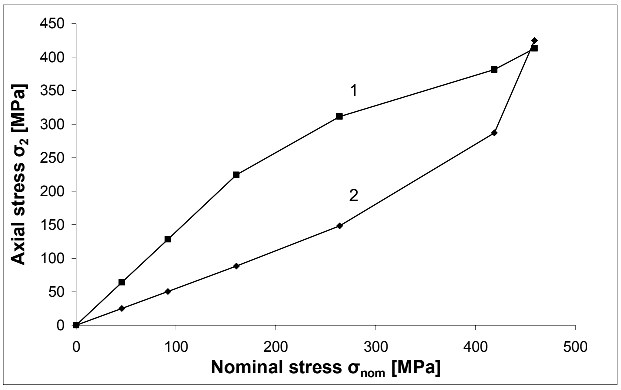

Fig. 5. The numerically determined relationship between nominal stress $\sigma_{nom}$ and axial stress $\sigma_2$ in the specimen axis - curve 2 and in notch – curve 1; notch radius ρ = 2 mm

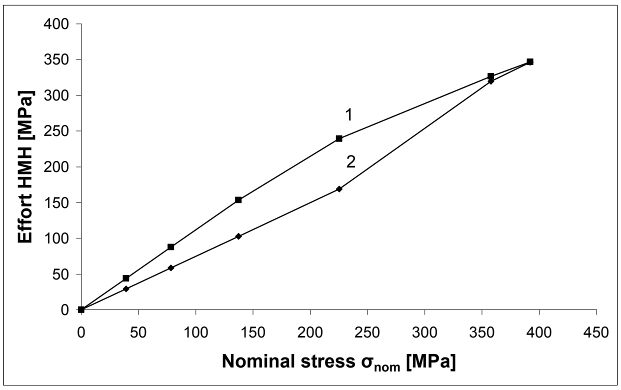

Fig. 6. The numerically determined relationship between nominal stress $\sigma_{nom}$ and effort (expressed by the HMH hypothesis) in the specimen axis - curve 2 and in notch – curve 1; notch radius ρ=7 mm

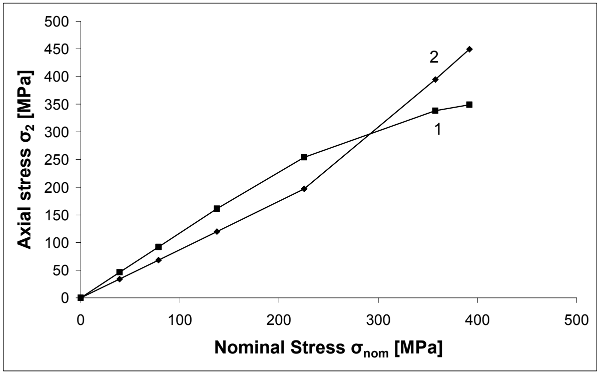

Fig. 7 The numerically determined relationship between nominal stress $\sigma_{nom}$ and axial stress $\sigma_2$ in the specimen axis - curve 2 and in notch – curve 1; notch radius ρ=7 mm

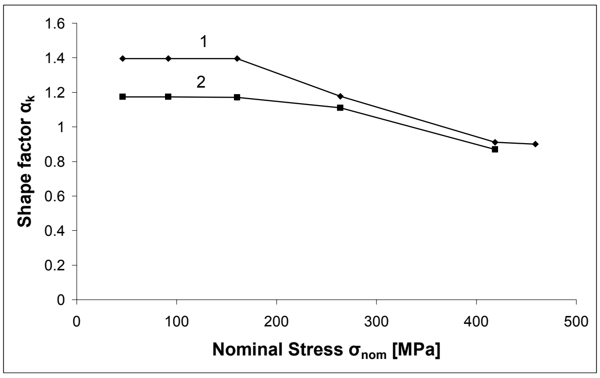

Fig. 8. The numerically determined relationship between the shape factor $\alpha_k$ and nominal stress $\sigma_{nom}$; curve 1 – notch radius $\rho = 2$ mm, curve 2 - notch radius $\rho = 7$ mm

The change of the notch radius also affects the place where stresses of the highest value occur. With the increasing tensile force and the notch radius $\rho = 2$ mm, the maximum stresses are located in the notch bottom, as shown in Figures 9A and 9B.

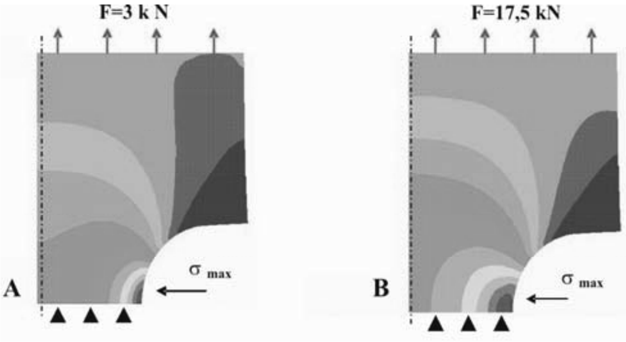

Fig. 9. The location of the regions of maximum stresses $\sigma_{max}$ (the red colour) in the cross-section of a specimen with the ring notch of $\rho = 2$ mm radius at the beginning of load application (Fig. A) and at the instant of failure (Fig. B)

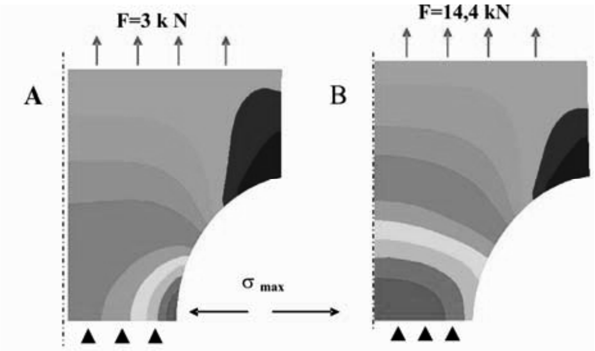

Fig. 10. The location of the regions of maximum stresses $\sigma_{max}$ (the red colour) in the cross-section of a specimen with the ring notch of $\rho = 7$ mm radius at the beginning of load application (Fig. A) and at the instant of failure (Fig. B)

# Conclusions

1. Changes in the size of the ring notch radius cause changes in the decohesion mode of the cast AlSi alloy.
2. In specimens plain and with the ring notch of 7 mm radius there are zones of ductile fracture; the fracture is of a brittle character when the notch is point-ended.
3. The change in notch radius is also responsible for the change in location of the areas of maximum stresses which, in the case of load increment and a notch of 7 mm radius, are moving from the notch tip to the specimen axis, while for a notch of 2 mm radius they invariably remain within the notch tip area.
4. The difference in the alloy decohesion mode is due to differences in the state of stress, which can be characterised by the, so called, degree of stress triaxiality, determined theoretically or numerically.
5. The conducted investigations indicate that the non-linear model of a stress-strain relationship, adopted in numerical computations, correlates well with the experimental results, while the linear solution expressed by the shape factor $\alpha_k$ neglects the alloy decohesion mode.

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