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Procedia Structural Integrity 28 (2020) 1930–1940

Structural Integrity Procedia

www.elsevier.com/locate/procedia

1st Virtual European Conference on Fracture

The Study of the Sensitivity of GTN Parameters

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Abstract

Gurson–Tvergaard–Needleman (GTN) model is a quite reliable tool that we can use to predict the failure of a component. Still, the determination of those parameters is not an easy task. It takes much time for computing, and sometimes we do find different sets of GTN parameters, with the same results after simulation. The purpose of this paper is to study how the change of the parameters affects the results, which means we are going to explore the non-uniqueness phenomena. We are going to conclude at the end, what are the main sensitive parameters.

Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

To ensure the Nuclear Safety of Nuclear power plants, we need to keep all the parts working correctly. With high performance, therefore the pipelines are one of these parts, the leakage problem in the pipes is a very critical issue that's might affect the performance of the Nuclear Power Plant if we did not detect it from the beginning and resolve it, Yassine et al. (2019).

Ductile fracture is the primary mode of failure in the case of pipelines, the physical process in ductile fracture involves the nucleation, growth, and coalescence of microvoids.

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10.1016/j.prostr.2020.11.016

The GTN model is a powerful tool that's used in the industry and the research area. Still, the determination of GTN parameters it is not an easy task. It required much time to find the right combination. Still, the problem is that with different sets of parameters, we could see the same results, so we need to study this phenomenon more by defining the most sensitive parameters.

1.1. Gurson model

GTN model, it is very known damage model that's widely used in engineering application to predict the failure of materials such as steel cast iron, copper, and aluminum and there are some studies which prove the usability of the model in the case of polymer also Alpay Oral et al. (2012)

Gurson Tvergaard and Needleman's damage model (GTN model) Gurson (1975) is an analytical model that predicts ductile fracture based on nucleation, growth, and coalescence of voids in materials.

The model is defined as:

$$\phi = \frac{\sigma_e^2}{\sigma_M^2} + 2q_1 f^* \cosh\left[\frac{tr\sigma}{2\sigma_M}\right] - \left(1 + q_1^{\ 2} f^{*2}\right) \qquad (1)$$

In which the parameter q_1 is the material constant, trσ is the sum of principal stresses, σ_M is the equivalent flow stress and f* is the ratio of voids effective volume to the material volume ratio defined as follows:

$$f^*\left(f\right) = f_c \text{ If } f \le f_c \qquad (2)$$

$$f^*\left(f\right) = f_c + \frac{\left(1/q_1\right) - f_c}{f_f - f_c}\left(f - f_c\right) \text{ If } f \ge f_c \qquad (3)$$

Where f is the voids volume ratio, f_c is the voids volume ratio at the beginning of nucleation, and f_f is the voids volume ratio when the fracture occurs.

σ_M is obtained from the following work hardening relation:

$$\sigma_M\left(\varepsilon_M^{pl}\right) = \sigma_y\left(\frac{\varepsilon_M^{pl}}{\varepsilon_y} + 1\right)^n \qquad (4)$$

In which n is the strain-hardening exponent, and ε_M is the equivalent plastic strain.

The voids growth rate is the sum of existing voids growth f_g and the new voids nucleation f_n

Where the components are further formulated as follows:

$$\dot{f} = \dot{f}_n + \dot{f}_g \qquad (5)$$

Where the components are further formulated as follows:

$$\dot{f}_g = \left(1 - f\right) tr \dot{\varepsilon}^{pl} \tag{6}$$

$$\dot{f}_n = A \dot{\varepsilon}_M^{pl} \tag{7}$$

$$A = \frac{f_n}{S_n \sqrt{2\pi}} \exp\left[-1/2\left(\frac{\varepsilon_M^{pl} - \varepsilon_N}{S_N}\right)\right] \tag{8}$$

In which $tr\varepsilon^{pl}=(\varepsilon_x+\varepsilon_x+\varepsilon_x)$ is the volume plastic strain rate, S_N is the voids nucleation mean quantity, fn is volume ratio of the second phase particles (responsible for the voids nucleation), and ε_N is mean strain at the time of voids nucleation.

So, GTN model involves eight parameters which can be defined in a vector form by:

$$\phi = \phi(q_1, q_2, f_0, f_c, f_n, f_f, \varepsilon_N, S_N)$$

2. Methodology and Results

According to the previous studies (Table 1), the values of q_1, q_2 are almost fixed, so we are going to deal with six parameters.

To study the sensitivity of GTN parameters and how the change of each parameter influences the results, we are going to follow these steps:

- Perform the small-scale test for Notch tensile specimens (the diameter is 10 cm) to provide the Experimental data and to get the stress-strain curve
- Make the Finite Element Simulations of the Notch specimen, the reason behind choosing Notch tensile specimens is because the simulation will take just 5 to 10 min and we can simulate just the quarter of the specimen due to the axisymmetry
- Make the simulations to study the effect of each parameter
- Perform the small-scale test for CT Specimen to provide the Experimental data and to get the stress-strain curve
- Make the Finite Element Simulations of the CT Specimen
- Check if the most sensitive parameters in the case of the Notch specimen are going to be sensitive; also, in the case of CT specimen, then we can conclude the change of the sensitivity between different geometries.

2.1. Notch Specimen experimental test

To determine the most sensitive GTN parameters on the results, We used the Notch tensile specimens and Compact tension specimen data. The main goal is to see the most sensitive parameters with the change of geometry.

According to the literature (Bauvineau et al. (1996); Decamp et al. (1997); Schmitt et al. (1997); Skallerud and Zhang (1997); Benseddiq and Imad (2008)), we were able to have initial values of GTN parameters as listed in Table 1 for steels.

Table 1 Gurson parameters according to litterature

References	q_1	q_2	E_N	S_N	f_0	f_c	f_n	f_f	Material
Bauvineau et al. (1996)	1.5	1	-	-	0.002	0.004	-	-	CMn Steel
Decamp et al. (1997)	1.5	1	-	-	0.0023	0.004	-	0.225	CMn Steel
Schmitt et al.(1997)	1.5	1	0.3	0.1	0	0.06	0.002	0.212	Ferritic base Steel
Skallerud and Zhang .(1997)	1.25	1	0.3	0.1	0.0003	0.026	0.006	0.15	CMn Steel
Benseddiq and Imad .(2008)	1.5	1	0.3	0.1	0	0.004-0.06	0.002-0.02	~0.2	

We took advantage of the symmetry, and we make the 2D FEM model just for the quarter of the Notch specimen and CT specimen, as shown in Fig. 1, and Fig.2

The set of GTN parameters that I'm going to study are, the determination of those GTN parameters was achieved by repeating the simulation multiple times until the simulation data fit the experimental data.

f_0 =Initial void volume fraction= 0.003

f_n=the new voids nucleation = 0.3

f_c=the voids volume ratio at the beginning of nucleation = 0.007

f_f =is the voids volume ratio when fracture occurs = 0.35

S_N =the voids nucleation mean quantity = 0.005

ε_n =strain at the time of voids nucleation = 0.065

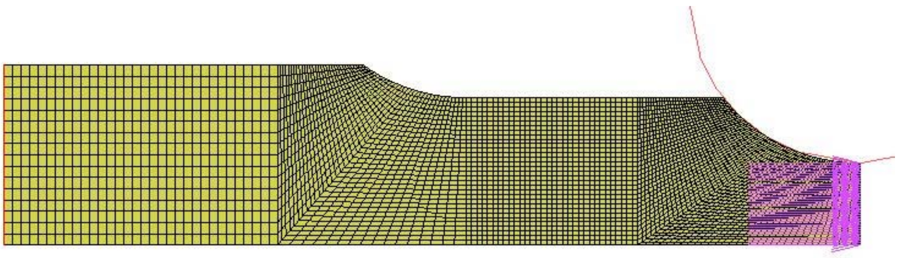

Fig 1. Notch Specimen simulation

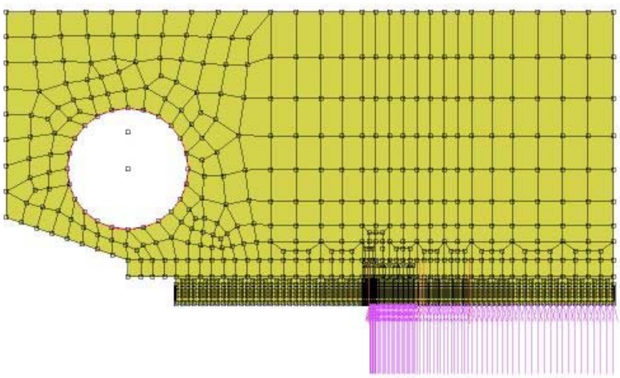

Fig 2. CT Specimen

2.2. *Study of the sensitivity of GTN parameters.*

To study how GTN parameters affect the results, we started by the notched specimen, and we have done for each parameter 20 simulations in which we tried to modify the value of one parameter and fix the others, in the end, We are going to be able to find the parameters that they are susceptible to small changes, after this, we are going to check if the most sensitive parameters in case of notch specimen would have the same effect in case of CT specimen or not

As already mentioned, we are going to deal with six parameters, because the values of q_1 and q_2 are almost fixed.

We have done 120 simulations in total for each parameter 20 simulations, and the results of the Force versus crack opening displacement (COD) for notch specimens are shown in the figures below.

f_0 = 0.003 (We made the variation of the parameter by this value ±0.0003)
f_n=0.3 (We made the variation of the parameter by this value ±0.03)
f_c=0.007 (We made the variation of the parameter by this value ±0.0007)
f_f =0.35 (We made the variation of the parameter by this value ±0.035)
S_N =0.005 (We made the variation of the parameter by this value ±0.0005)
ε_n =0.065 (We made the variation of the parameter by this value ±0.0065)

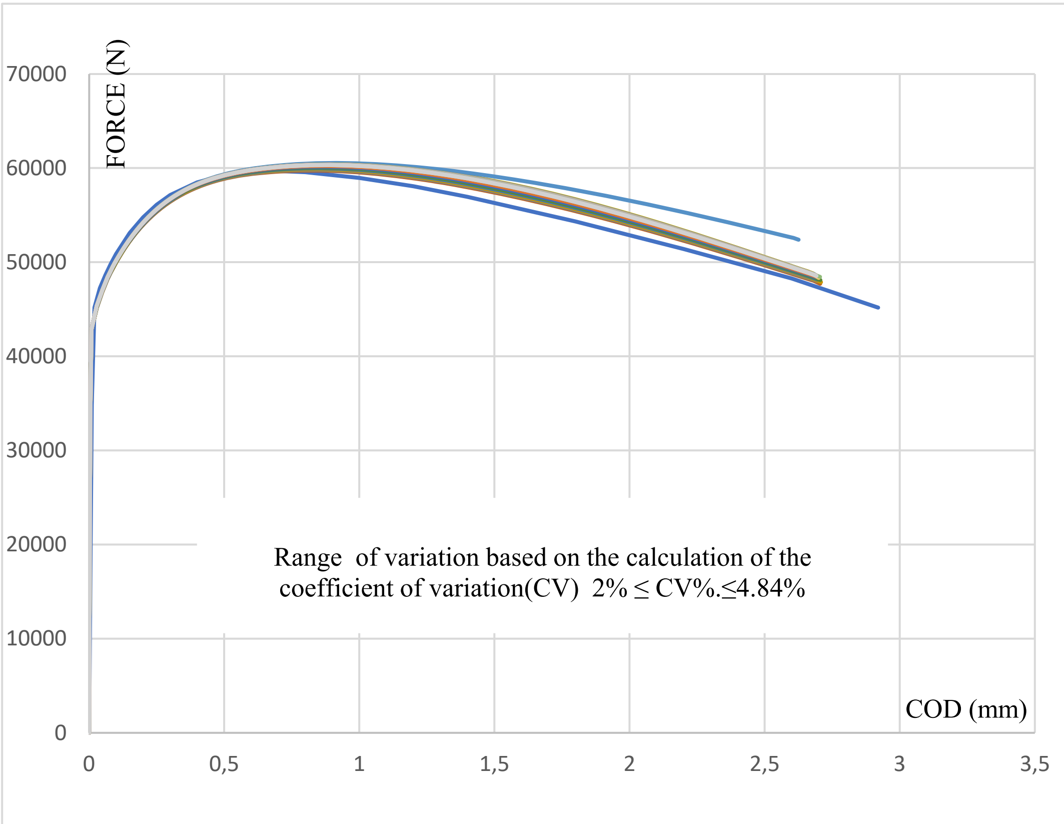

Fig 3. The variation of the Initial void volume

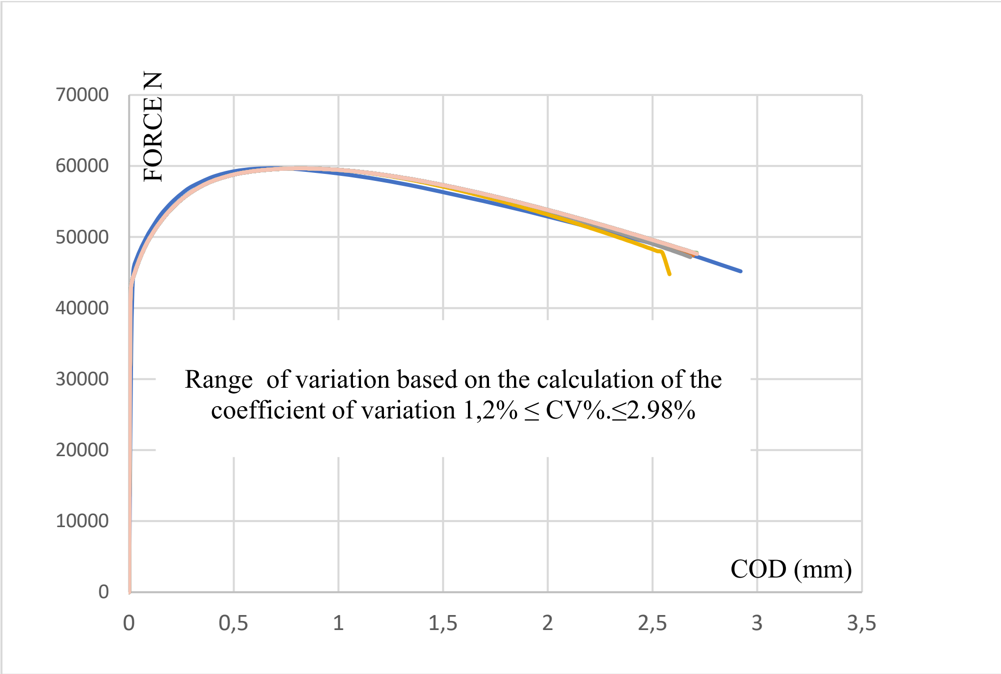

Fig 4 the new voids nucleation

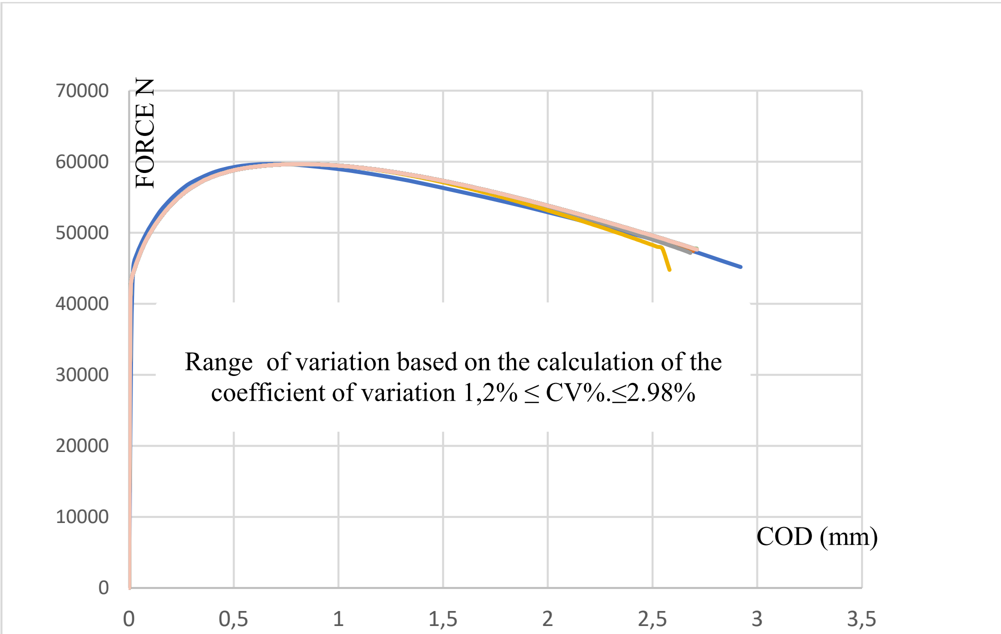

Fig 5. The variation of the voids volume ratio at the beginning of nucleation fc

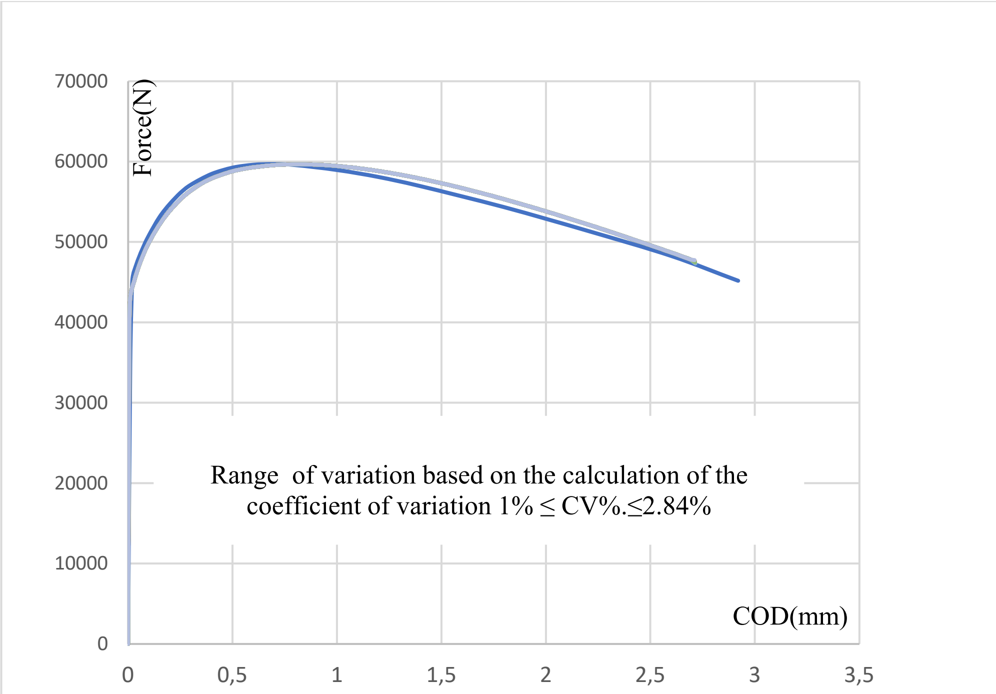

Fig 6. The change of voids volume ratio when the fracture occurs

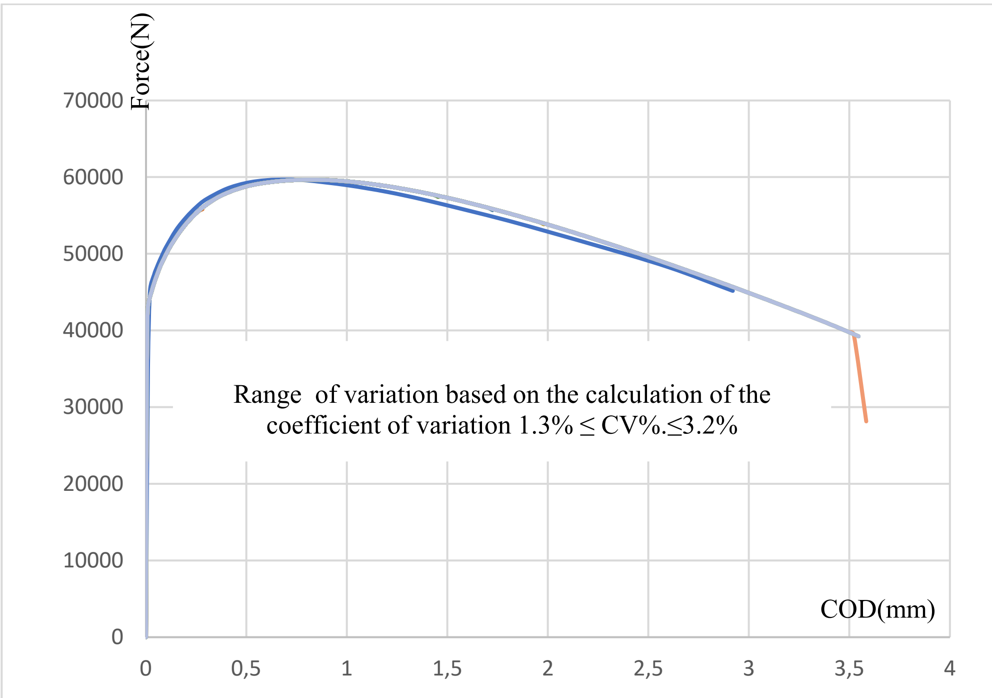

Fig 7. strain at the time of voids nucleation εn

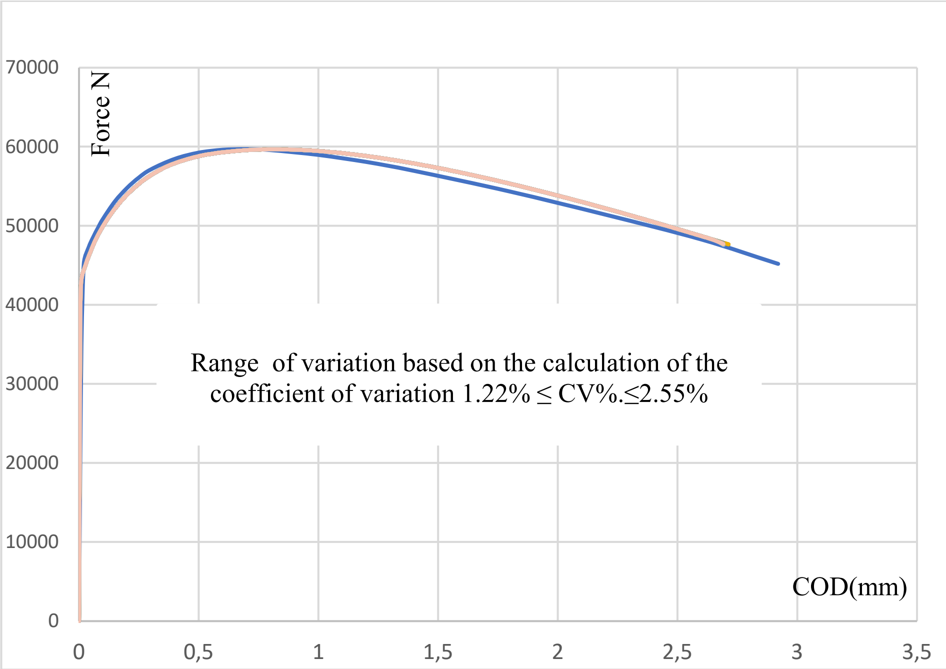

Fig 8. The voids nucleation mean quantity Sn

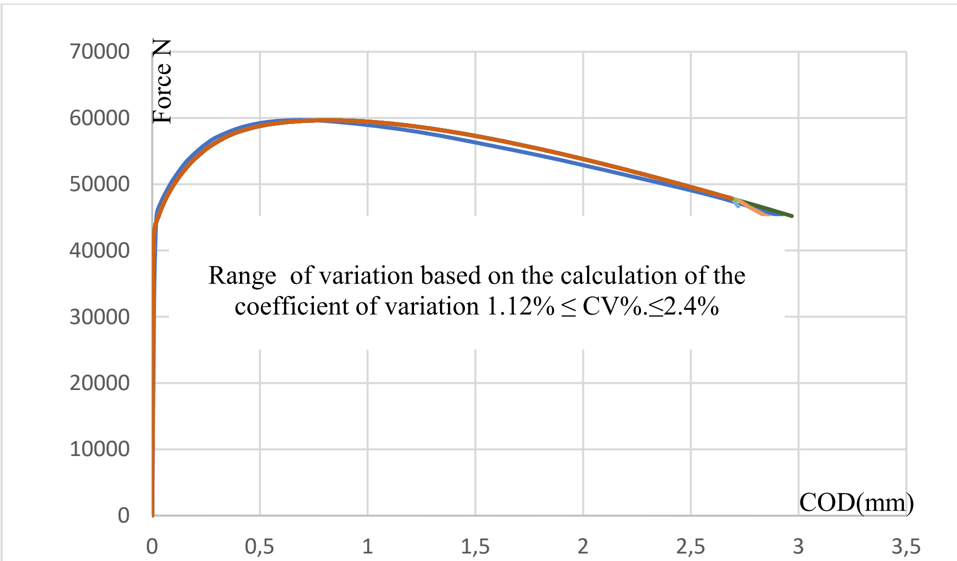

Fig 9. new voids nucleation f_n

As we can see in the results, the initial void volume fraction f_0 is the most sensitive parameter to a small change in its value.

We can conclude that the determination of the exact value of f_0 has to be more precise, and it should have physical meaning and respect the values mentioned in Table 1.

For the parameters f_c, f_f, ε_n, f_n, and S_n, the difference between the stress-strain curves are very slight.

It seems that the change of the parameters f_c, f_f, ε_n, f_n, and S_n, values will not affect the failure prediction macroscopically.

It not possible to launch any simulation when the value of f_f is lower than the value of f_c

The next step is to determine the sensitive parameters in the case of CT specimen.

We have done ten simulations for each parameter, and each simulation took six hours.

The results of the Force versus crack opening displacement (COD) for CT specimens are shown in the figures below.

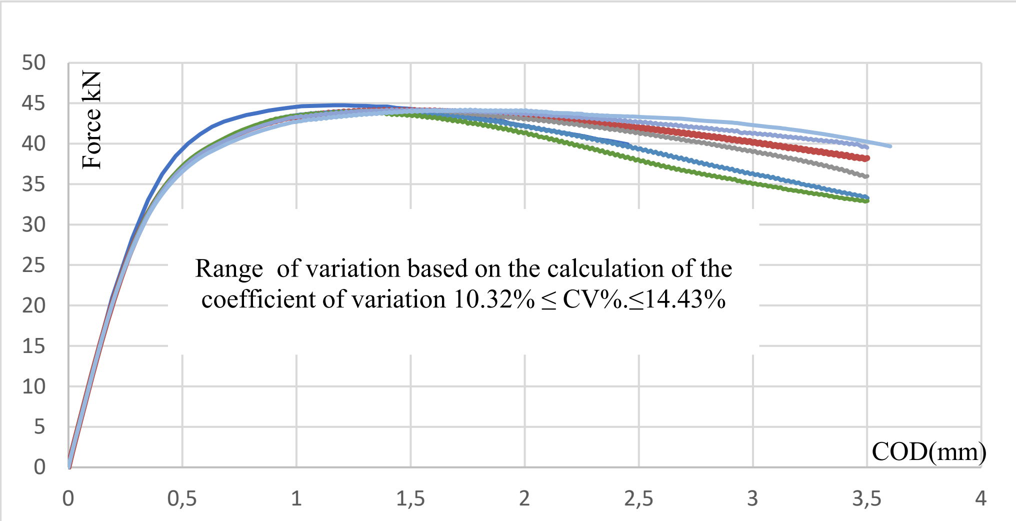

Fig 10. Initial void volume fraction f

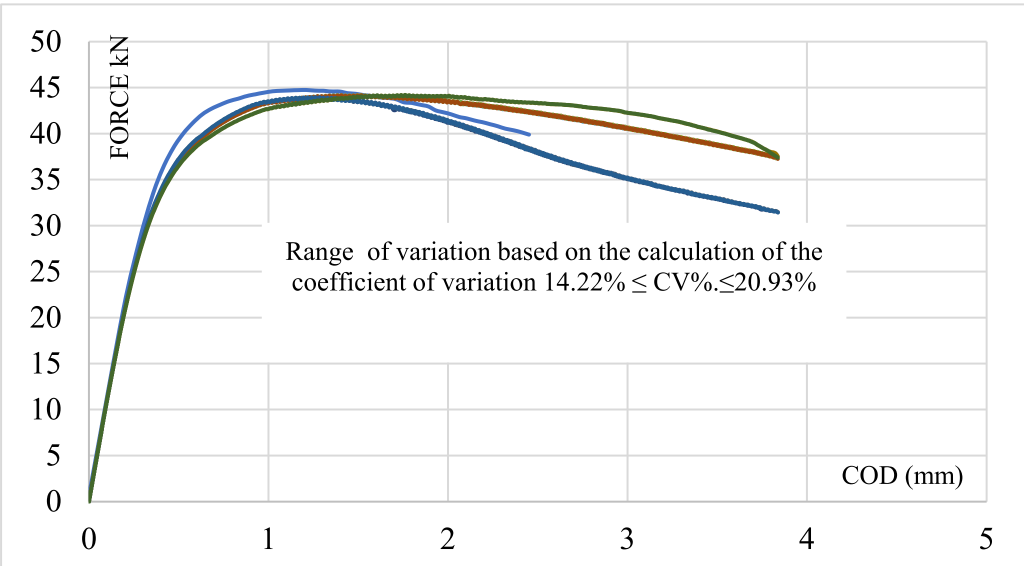

Fig 11 the voids nucleation means the quantity

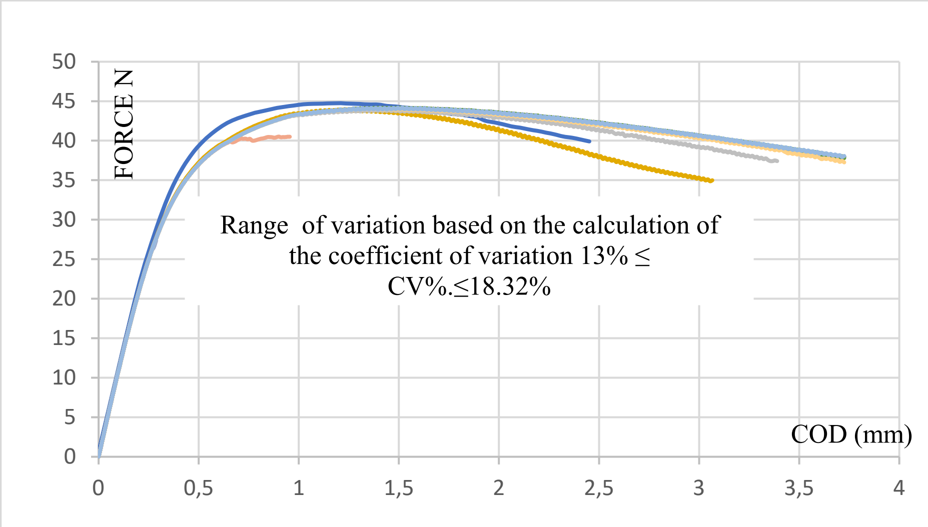

Fig 12 strain at the time of void nucleation

By analyzing the curves, it is evident that the variation of the parameter f_0 influences the results, in addition to this, and comparing to the results that we got in case of notch specimen. It is noticeable that in the case of CT specimen, the parameter f_0 becomes more sensitive to small changes. New parameters become sensitive which are the voids nucleation means quantity and strain at the time of void nucleation, we can conclude that the sensitivity of the mentioned parameters become noticeable due to the geometry, and also the change of the applied load, more studies will be done to check the variation of parameters compared to other geometries, a microscopic study will be done to check the variation of the most sensitive parameters.

According to what is shown in Table 1, the Gurson parameters are not fixed, and they depend on the type of the material; in addition to this, we can find a different set of parameters giving the same results as the experience. However, at the microscopic level, they are different regarding the crack initiation and propagation.

The results that we got in this study show that the most sensitive parameter is f_0, $\varepsilon_{n,}$ and $S_{n.}$

3. Conclusion

the GTN model is a powerful and applicable tool in the research and industry; to be able to use this model, we need the right combination between the eight GTN parameters.

As a conclusion of this work, we did perform 180 Simulations (120 for NT and 60 for CT) to study the most sensitive parameters that affect the prediction results. We did choose the notched specimen because it did not require a lot of computing time. We choose another geometry, which was a CT specimen, to see if the most sensitive parameters in the case of the Notch specimen have the same effect on CT specimens.

The results showed that the parameters f_0, $\varepsilon_{n,}$ and S_n are the most sensitive. For $f_{c,}$ f_n the effect of the change of those parameters is not very big, and the evolution should be studied at a microscopically level.

More studies should be done to find a suitable way to find the correct set of parameters which could describe in microscopic level the crack initiation and propagation

Acknowledgments

This work was carried out as part of the Advanced Structural Integrity Assessment Tools for Safe Long Term

Operation project. The European Union supports the realization of this project.
This work was carried out in part in Bay Zoltán Alkalmazott Kutatási Nonprofit Kft Miskolc.

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