On monitoring of mechanical characteristics of hot rolled S355J2 steel

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ABSTRACT. Hot rolling normalization technology for producing sheets from a low-carbon steel, Steel S355J2, used in the Bulgarian Metallurgical Plant "STOMANA Industry SA" is under investigation. A newly introduced automatic application optimization procedure in this technology is an important step that leads to avoiding of traditional heat treatment, improving of steel mechanical characteristics, increasing of production efficiency, all resulting in high quality final products. On the basis of the final mechanical rolled-sheet characteristics - yield strengths, R_e, ultimate tensile strengths, R_m, absorbed energies in impact tests, K, and elongations after fracture - some energy-stress and energy-stress-elongation constructions-spaces have been plotted. These spaces can be used for general evaluation of the applied rolling technology and for prediction of steel-sheet mechanical behaviour.

KEYWORDS. Hot Rolling; Low-Carbon steel S355J2; Rolled-sheet; Prediction of Steel-Sheet Mechanical Behaviour

INTRODUCTION

Development of modern metallurgy and engineering is characterized not only by increasing production volume and enriching production range, but by sufficient improve in quality - increase of metal-product's service life in combination with high reliability of structures machines and devices [1-3].
Industrial processing of metals (forming) by plastic deformation is one of the major and most important industries in the global economy. High quality metal product features a constant chemical composition, micro- and macrostructure, geometric shapes and sizes and guaranteed physical and mechanical properties. The quality of metal products depends primarily on their mechanical properties, their behavior in processing and exploitation, and their microstructure [1-5].

EXPERIMENTAL WORK AND RESULTS

Conventional hot rolling technology for producing thick sheets

Thick sheets (30 mm and 40 mm) from a low-carbon steel, Steel S355J2+N, have been produced by normalization rolling in the Bulgarian Metallurgical Plant "STOMANA Industry SA" for more than 60 years [6-7].
The aim of this work is to investigate and control the technological process of forming of hot-rolled steel plate (sheet) of Steel S355J2+N in attempt to improve mechanical characteristics of the final product.

Standard chemical composition and mechanical properties

Steel S355J2+N is low-carbon, low-alloy structural steel with chemical composition shown in Tab. 1 and mechanical properties presented in Tab. 2, both accordingly the standard EN 10025-2:2004 "Hot rolled products of structural steel".

C	Mn	Si	P	S	Cr	Ni	Cu	Mo	As	Al	V	Ti
0.16-0.18	1.10-1.16	0.20-0.26	0.008-0.014	0.002-0.010	0.040-0.120	0.060-0.150	0.180-0.320	0.009-0.031	0.008-0.027	0.025-0.040	0.031-0.042	0.022-0.037

Table 1: Chemical composition of Steel S355J2+N (weight %)

Yield strength, R_e, MPa	Tensile strength, R_m, MPa	Total Elongation, A, %	Impact test*, K, J
345 - 430	470 - 630	min 20 – 22 %	min 27 *

* test piece with V-figurative notch; T= - 20°C

Table 2: Mechanical Properties of Hot-Rolled Sheet's Steel S355J2+N with nominal thickness 30 and 40 mm

Equipment and technological experiments

According to EN 10025-2:2004, 40 experiments have been carried out – two groups of 20 experiments to obtain two different thicknesses of the finished product (final plate/sheet), respectively of 30 mm and 40 mm. Rolling mill used is schematically represented in Fig. 1 as a complex of mechanical components and equipment for hot rolling of heavy plates/sheets, their further processing and transportation. The mill consists of a reverse Roll Mill type "Quarto", and equipment for straightening, cutting and marking of finished products [6-7].

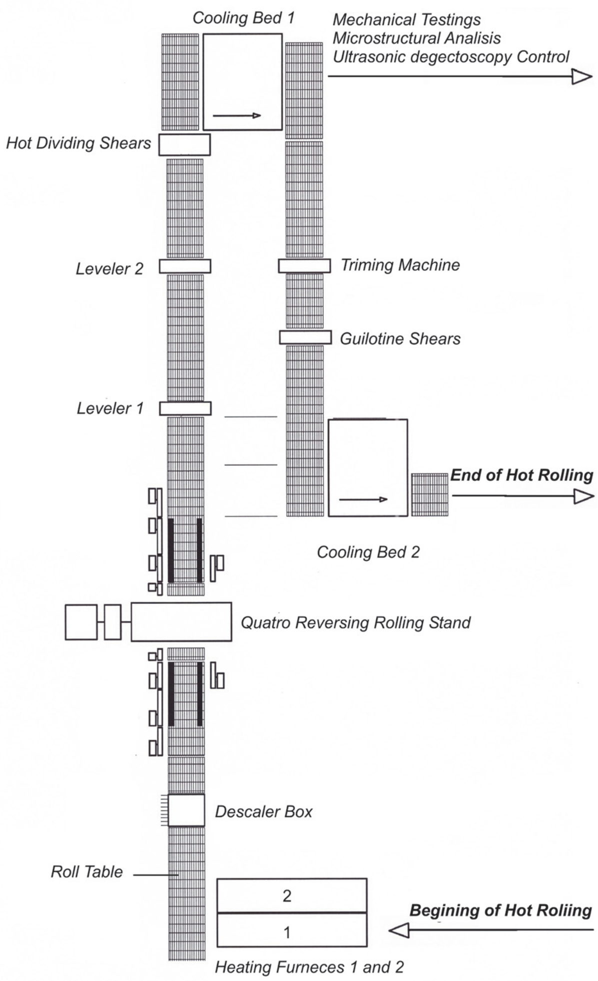

Figure 1: Scheme of Quarto Reversing Rolling Stand for hot-rolled steel plates/sheets in the Bulgarian Metallurgical Plant "STOMANA Industry SA".

To adjust the parameters of the rolling mill for receiving quality products with desired properties by total thickness of 30 mm and 40 mm, there were developed and experimentally tested two speed-temperature-deformation regimes - *Regime A* and *Regime B*. Each profile size (30mm and 40mm) is obtained, performing deformation process in these two regimes; 10 pieces from each thickness are tested.

Specific features of the different rolling regimes

Regime A. Rolling process is carried out when the parameters of the rolling mill are set up as follows: large rolling forces (up to 75% of the maximum for the mill or up to 16,000 kN); high torque (running over to the equipment nominal value); large difference between the initial and the final thickness of the metal concerning each pass, ΔH [mm], respectively a high degree of deformation (reduction in thickness into each pass about 20%). Speed-temperature-deformation normalization rolling for *Regime A* is designed with 21 passes.

Regime B. Normalization rolling process is performed with new setting of the parameters of the rolling stand, providing less stress (up to 68%), a low torque, small difference between the initial and the final thickness of the metal concerning all passes (ΔH is between 13 and 16 mm) and decreased deformation, respectively to maximum 16-20%. All this leads to an increase in the number of passes to 25. Under these initial conditions and using an automatically applied optimization program, *Regime B* has been developed as a more efficient one.

Testing

After rolling, 40 specimens were machined for standard mechanical testing – 20 for *Regime A* and 20 for *Regime B*, of which 10 specimens for the final thickness of 30 mm and the same quantity for the thickness of 40 mm. Data obtained from testing concern mechanical (tensile strength, yield strength) and plastic (elongation) behaviour (of the final product), as well as impact energy providing information about impact strength. They (the data) are presented in Fig. 2.

DISCUSSION AND ANALYSES

The data presented in Fig. 2 show that the final products obtained in *Regime B* have improved mechanical behaviour, corresponding to the standard EN 10025-2:2004, when the plates obtained by using *Regime A* cannot satisfy the requirements of this standard.

This means that the rolling process of *Regime A* is unstable in comparison to the stable one under *Regime B*, wherein the rolling process is controlled, which leads to a sufficient improve of all mechanical properties and their steady reproduction.

Usually mechanical testing results have the standard presentation as can be seen in Fig. 2, following by standard analysis. But these results can be presented in a new different way as it has been done in Fig. 3a and 3b. The Fig. 3 visualizes Energy-Stress Constructions-Spaces $MNLQQ_1M_1N_1L_1$ for 30 mm and 40 mm plates/sheets (obtained under *Regime B* including automatic application of the mentioned above optimization procedure), which are built by using the final mechanical rolled-plate characteristics - yield strengths, R_e, ultimate tensile strengths, R_m, absorbed energies in impact tests, K. (Elongations after fracture are included in similar Constructions-Spaces in Fig. 5.) These Constructions-Spaces bring additional information about rolling technology and energy-mechanical properties of the finished/final products. The complicated three-dimensional Energy-Stress Surface MNLQ in Fig. 3a and 3b shows that although the minimum values of yield strength and tensile strength are above the minimum set by the standard, it is worth looking for further improvement of the speed-temperature-deformation regime of rolling that will make this surface smoother, meaning further (even higher) stabilization of technology and energy-mechanical properties of the finished/final product. At the moment Surface MNLQ looks smoother for 30 mm plates/sheets than that for 40 mm ones.

In Fig. 4a and 4b complex pyramidal Spaces $STUT_1S_1P$ have been built, each by:

- the straight lines PU and S_1T_1 of the average values of yield strengths and tensile strengths respectively, corresponding to the 10 tests for each thickness; and
- the broken line ST, obtained from the average energy of impact tests and the stresses $(R_{m,av} - R_{e,av})/2$ (corresponding to the same 10 tests).

It is easy to build a line corresponding to the average value of the stresses from the broken line ST. Thus the visualization of the pyramidal Spaces $STUT_1S_1P$ makes it possible to predict dispersion of all stresses from the range between the yield strength and the tensile strength, enabling us to do some preliminary comparisons with the exploitation stress requirements.

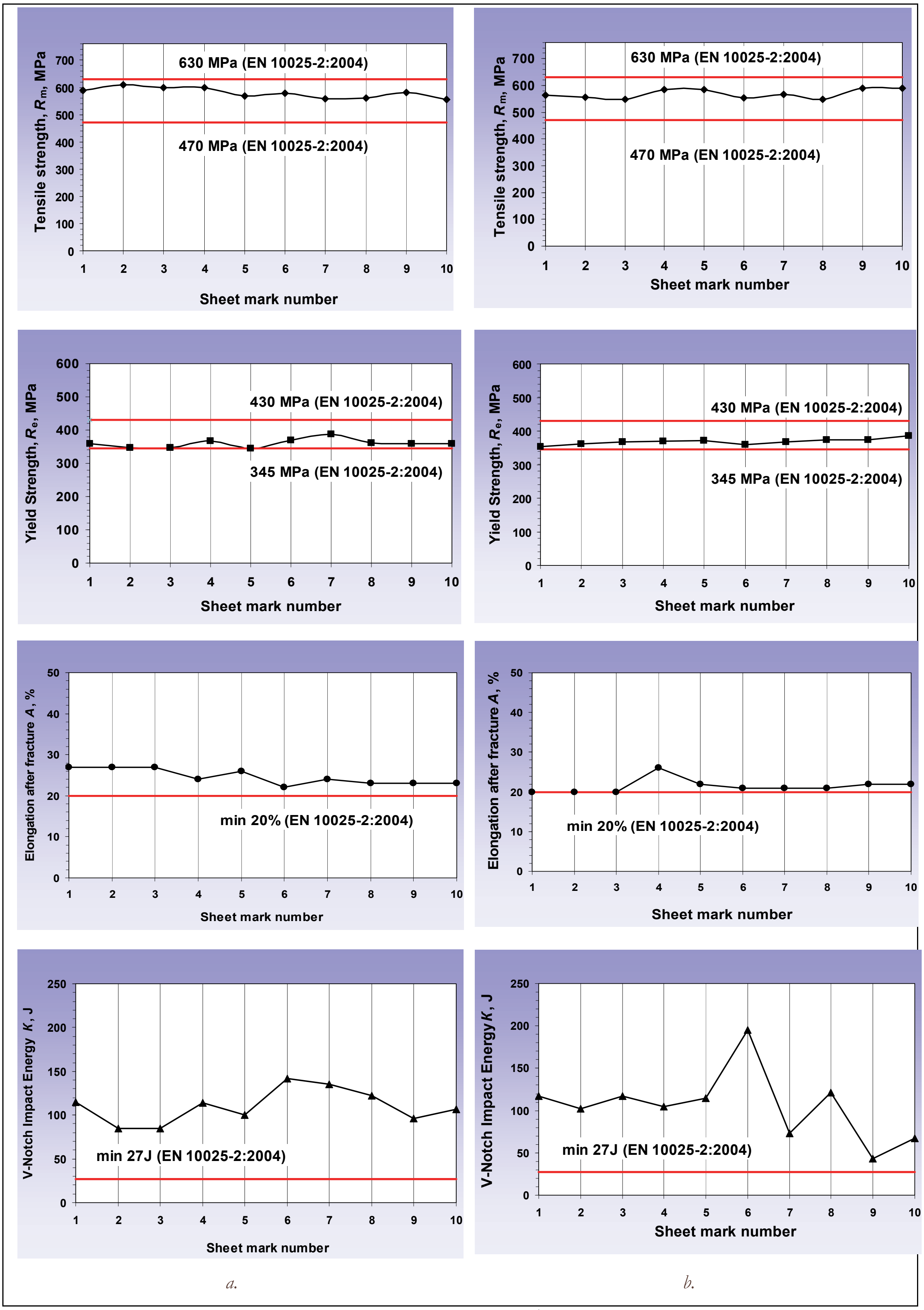

Figure 2: Comparative analysis of mechanical properties of hot-rolled plate/sheet, obtained by strain–speed–temperature Regimes A and B; a. – plate/sheet with final thickness 30 mm; b. – plate/sheet with final thickness 40 mm.

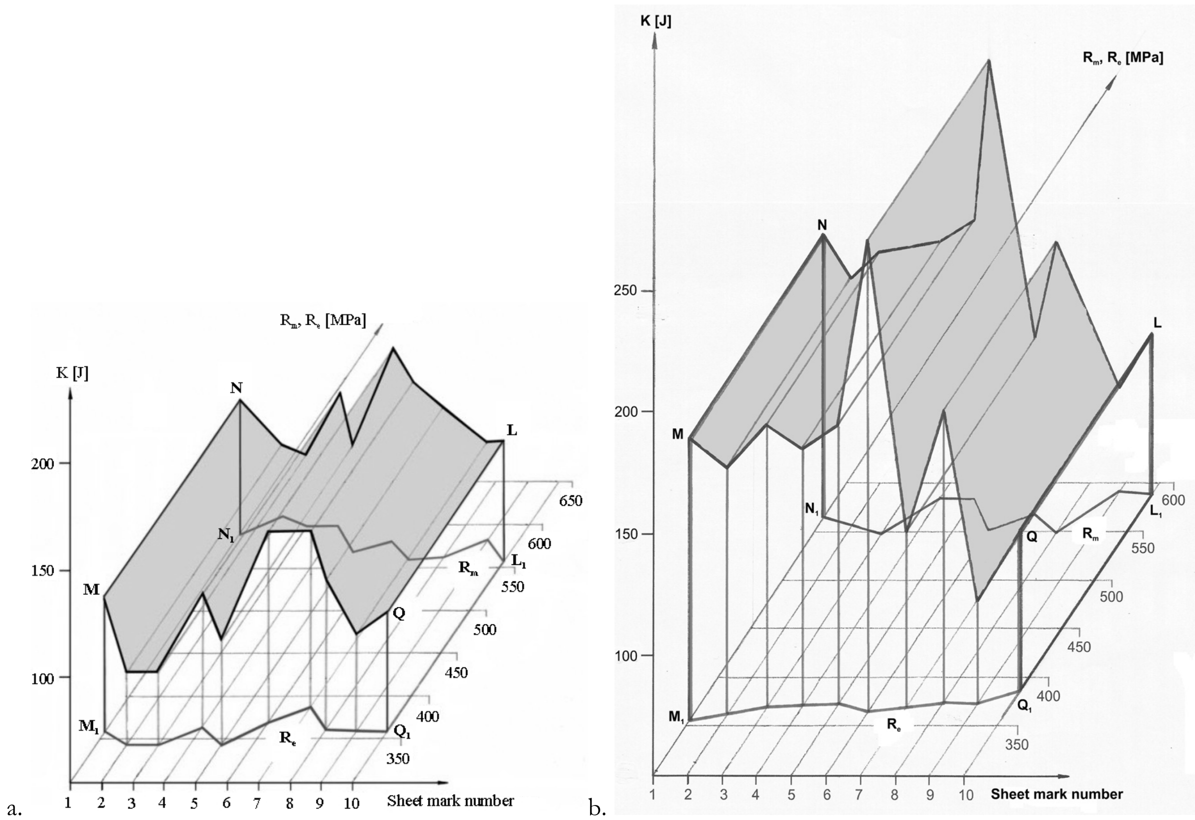

Figure 3: Energy-Stress Constructions-Spaces $MNLQQ_1M_1N_1L_1$, expressing mechanical behaviour of: a. - 30 mm plates/sheets; and b. - 40 mm plates/sheets.

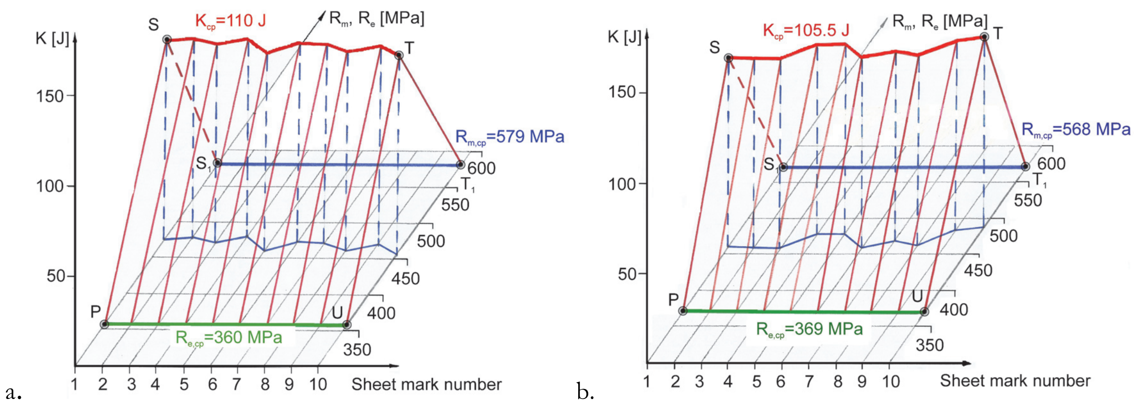

Figure 4: Pyramidal Spaces $STUT_1S_1P$, presenting a basis for predicting mechanical behaviour of: a. - 30 mm plates/sheets; and b. - 40 mm plates/sheets.

On the basis of Fig. 3, Energy-Stress-Elongation Construction-Space $MVZQQ_1M_1V_1Z_1$ has been plotted and shown in Fig. 5.

It includes elongation after fracture, plotted for all stresses of the broken line NL, which moves the line NL to its new position, the broken line VZ. The Construction-Space $MVZQQ_1M_1V_1Z_1$ includes all energy, stress and elongation characteristics of the final product and can be used as an instrument for general evaluation of the applied rolling technology and for prediction of steel-sheet mechanical behaviour, including plasticity, under exploitation conditions [3, 4]. Transition from the Space $MNLQQ_1M_1N_1L_1$ to the Space $MVZQQ_1M_1V_1Z_1$ can be done through the plotted in Fig. 5, Stress-Elongation Area NVZL.

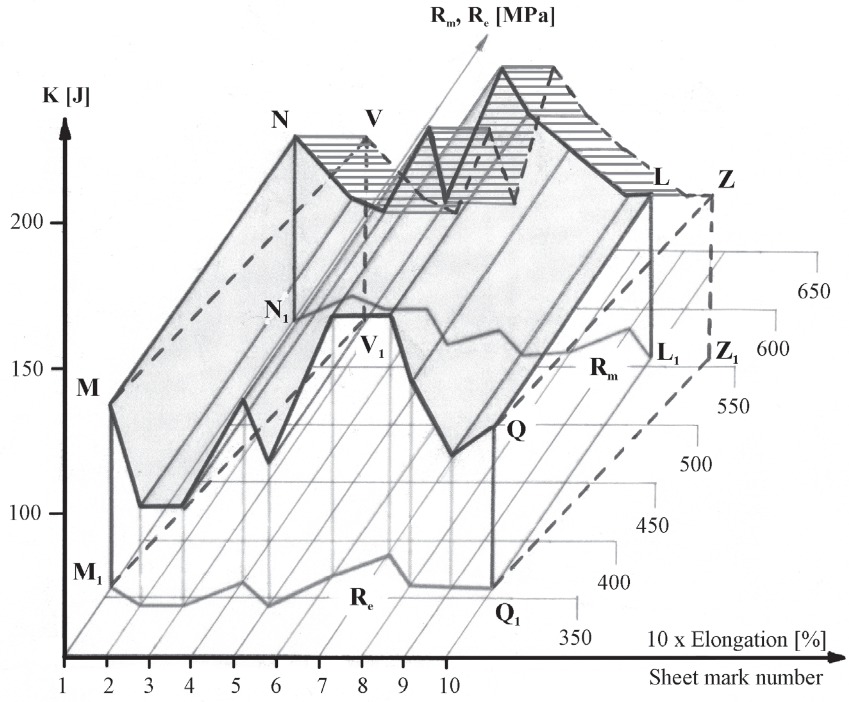

Figure 5: Energy-Stress-Elongation Constructions-Space $MVZQQ_1M_1V_1Z_1$, expressing mechanical behaviour, including plasticity, of 30 mm plates/sheets

CONCLUSION

The technological process of obtaining hot-rolled steel plates/sheets of steel S355J2 + N has been investigated aiming at improving mechanical characteristics of the final product. Two different regimes of normalization rolling have been studied (carrying out 20 experiments per regime) – the basic *Regime A* and a newly designed *Regime B* (including automatic application optimization procedure) – and *Regime B* is found and proved to be the more efficient one. Using standard test data characterizing mechanical (tensile strength, yield strength) and plastic (elongation) behaviour of the final product, as well as impact energy providing information about impact strength, some Energy-Stress and Energy-Stress-Elongation Constructions-Spaces have been built. These spaces can be used as an instrument for general evaluation of the applied rolling technology and for prediction of steel-sheet mechanical behaviour under exploitation conditions. Transition from one space to the other can be done through a specific stress-elongation area, including the elongation after fracture.

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