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INFLUENCE OF THE DRECE PROCESS OF SEVERE PLASTIC DEFORMATION ON THE MECHANICAL PROPERTIES OF THE ULTRA-LOW CARBON INTERSTITIAL FREE STEEL

This research paper shows the influence of a repeated SPD (Severe Plastic Deformation) plastic forming with the DRECE technique (Dual Rolls Equal Channel Extrusion) on hardening of low carbon IF steel. The influence of number of passes through the device on change of mechanical properties, such as tensile strength TS and yield stress YS, of tested steel was tested. The developed method is based on equal channel extrusion with dual rolls and uses a repeated plastic forming to refinement of structure and improve mechanical properties of metal bands [1-2]. For the tested steel the increase of strength properties after the DRECE process was confirmed after the first pass in relation to the initial material. The biggest strain hardening is observed after the fourth pass.

Keywords: sheet metal, high strength steel, interstitial free steel, SPD process

1. Introduction

The automotive industry uses cold forming processes of metal sheets to a large extent for manufacturing body elements with complex shapes. Low carbon IF (Interstitial Free) steel is one of the materials, which due to good plastic properties, is used for deep drawing items in the automotive industry. These steels are characterized by a single phase ferritic structure and do not contain interstitial elements, i.e. carbon and nitrogen, in solid solution. This structure results in low strength of IF steels. Lower strength in such materials forces use of thicker metal sheets in order to maintain desired mechanical properties. This makes vehicles heavier and fuel consumptions increases. The low strength of IF steel limits its greater use in conditions where except of high plasticity also a high strength is required. Increase of mechanical properties while maintaining good plastic properties can increase potential use of IF steels not only in automotive industry but also in new areas, among others in aerospace and defence industries [3-5].

In recent years the interest in using unconventional SPD (ang. Severe Plastic Deformation) methods to obtain materials with ultra-fine-grained structure has significantly increased. Grain refinement favours above all increasing the strength properties of the material. Such methods include among others: DCAP (Dissimilar Channel Angular Pressing), AARB (Asymmetrical Accumulative Roll Bonding) and DRECE (Dual Rolls Equal Channel Extrusion) [5-9]. The DRECE method is based on the DCAP method (Dissimilar Channel Angular Pressing) and ECAP – CONFORM (Continuous Forming) and is intended for forming metal sheets or bands with maximum dimensions of 1000×60×2 mm. The material is introduced into the working space and then extruded through the feed roller by means of pressure rollers through the shaping tool without changing cross-section of the material. Multiple plastic deformations carried out this way influence the change of the structure and mechanical properties in relation to the initial material. The decisive factor for increasing mechanical properties of material after extrusion in the DRECE process is selection of the optimal forming angle in the plastic area (123°, 118° or 108°) determined by the structural arrangement of the forming tool and number of passes through the device [10-15]. Fig. 1. presents the principle of operation and a general view of the DRECE device.

SPD methods such as: DCAP, ECAP – CONFORM or AARB differ significantly from each other in the method of deformation, the impact of the tool on the deformed material,and the value of deformation in a single cycle [15]. In the DRECE method the degree of deformation obtained during a single pass through the forming tool is not as high as in the ECAP method, however, multiple plastic deformation carried out *without changing the cross sectional of the material* significantly affects structure subdivision to ultra metric sizes and change of mechanical properties. Most SPD methods are based on deformation of material being in a shape of bars or small pieces of metal sheets (ECASE – Equal Channel Angular Sheet Extrusion). DRECE, however, allows deformation of material in a shape of a metal sheet with much bigger dimensions than in other methods. This

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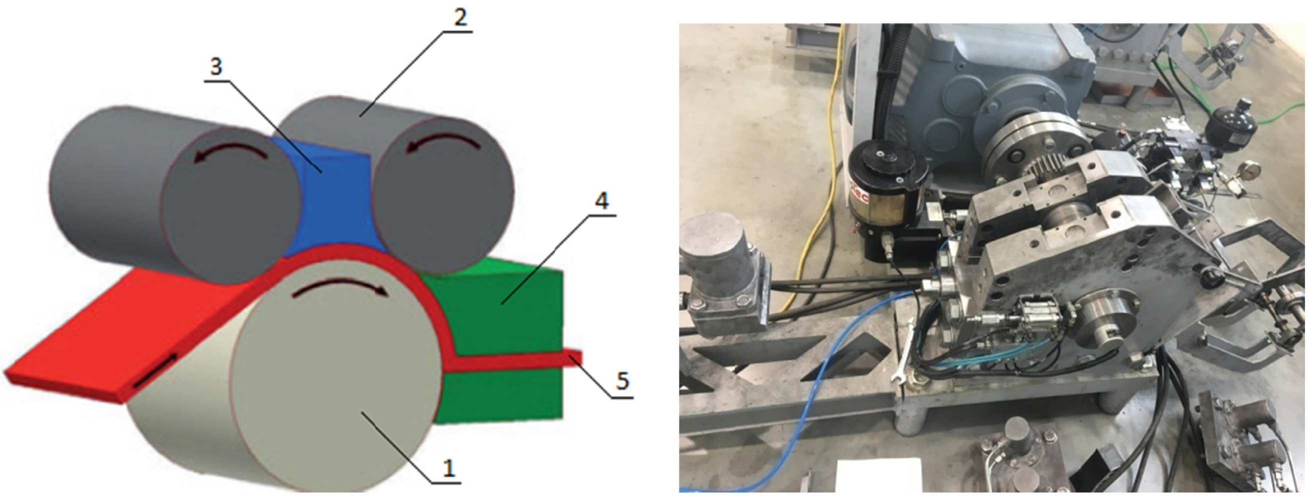

a.) b.)

Fig. 1. a.) Principle of the DRECE process; 1 – feed roller, 2 – pressure roll, 3 – forming tool, 4 – forming tool with forming angle (α = 108°), 5 – sheet sample; b.) DRECE equipment

device is unique in Europe, since the process of structure refining in flat blanks is ate present still under development. This is vital in the context of the future use of such material. Similarly to other SPD methods the material deformed with the DRECE technique is characterized by heterogeneity of obtained structure. Currently, works to improve this method and increase the efficiency of the process are being held [1-2, 15].

The paper presents results of studies of mechanical properties of IF steels formed in an unconventional SPD process i.e. DRECE.

2. Experimental procedure

The tested material was a thin low carbon IF metal sheet steel. It was cold rolled up to thickness of 2 mm and then annealed at the temperature of 850°C with holding time of 25 min. and air cooling [16-17]. IF steel is characterized by single phase ferritic structure (Fig. 2.) with hardness of 110 HV1 and tensile strength of 268 MPa. The chemical composition of tested steel is shown in Table 1.

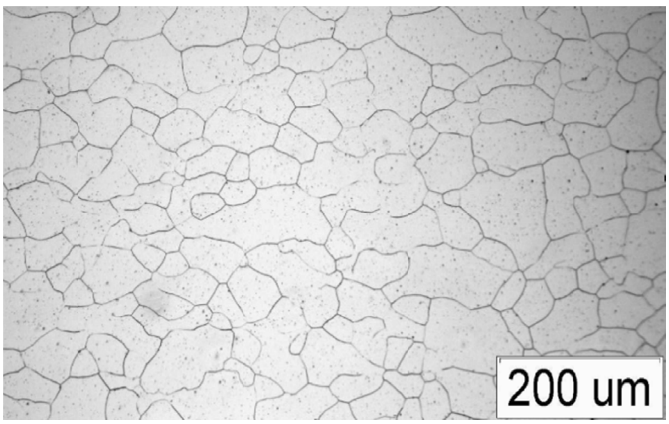

Fig. 2. Structure of IF steel – initial state; light microscope

TABLE 1

The chemical composition of IF steel (wt.%)

C	Mn	Si	Cr	N	Cu	Al	V	Ti	S	P
0.002	0.12	<0.005	0.019	0.005	0.02	0.029	0.001	0.059	0,008	0,009

The SPD researches with the unconventional DRECE method were held at VŠB – Technical University in Ostrava in the Department of Mechanical Engineering. α angle in the deformed zone was 108°. The charge was metal sheets with dimensions of 640.000 mm^3 (the metal sheet with the initial thickness of 2 mm, width of 40 mm and length of 800 mm. There were eight passes of the material and each subsequent pass was carried out without changing the orientation of the metal sheet in regard to the initial position after first pass. Before every pass through the DRECE devise the surface of the sheet was covered with Gleit grease – μ HP 515 used to reduce friction between the tool and tested material. The pressure on the feed roller was 150 bar, while on the pressure rollers (before the deformation zone) 30 bar. The pass of the material through the DRECE device was carried out at speed of 40 mm/min.

The change of mechanical properties after the plastic deformation and influence of number of passes through the DRECE device on mechanical properties of IF metal sheets was researched with static tensile test. The research was carried out on a series of three samples using a conventional testing machine ZWICK with a maximum force of 100 kN according to the PN-EN ISO 6892-1: 2010 standard. Samples with a rectangular cross-section were used (dog-bone). Dimensions of sample is shown in Fig. 3. Each sample was taken from a spot parallel to the direction of deformation.

The hardness of the tested steel was measured after tensile test. Hardness measurement was performed on longitudinal polished section with a load of 100g (HV0.1) with a step of 1 mm with a hardness tester of Struers Duramin-5 type.

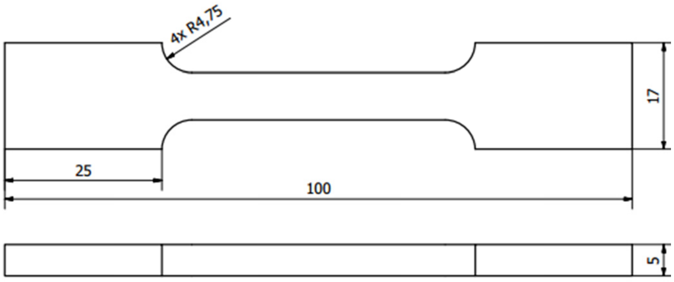

Fig. 3. Dimensions of sample for the static tensile test, given in mm

3. Results and discussion

The stress-strain characteristics of the IF steel are shown in Fig. 4. The obtained results of mechanical properties of IF steel after DRECE deformation are shown in Fig. 5 and in the Table 2. As a result of use the DRECE deformation the tensile strength of the IF steel has increased after the first pass to 296 MPa which is approximately 10% growth of the tensile strength in relation to the initial state. After fourth pass it reaches tensile strength equal to 348 MPa which means that there has been 30% increase of tensile strength in relation to the initial material. Yield stress for the steel in the initial state is 121 MPa. After first pass it increases to 276 MPa, and after fourth pass it is 326 MPa. Further increasing the number of passes does not increase the mechanical properties. Tensile strength after eighth pass is 338 MPa and yield stress is 319 MPa.

Also there was the indicator YS/TS calculated constituting so called reserve of plasticity. This value of in the initial material is 0.45. After first pass YS/TS increases to 0.93. This means a significant increase of the value of the reserve of plasticity of the

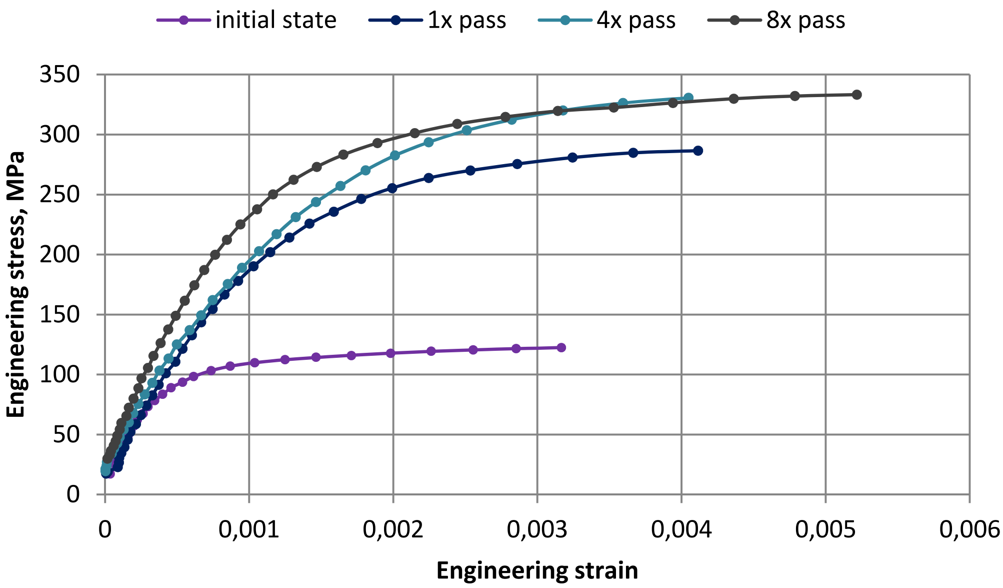

Fig. 4. The stress-strain characteristics of the IF steel in the initial sample and after DRECE process

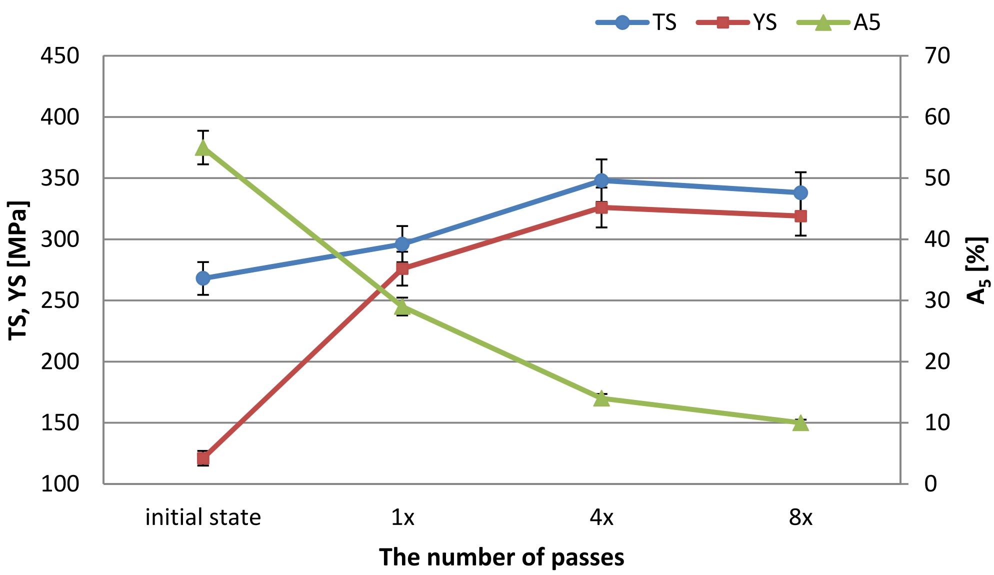

Fig. 5. Influence of pass number on mechanical properties of IF steel

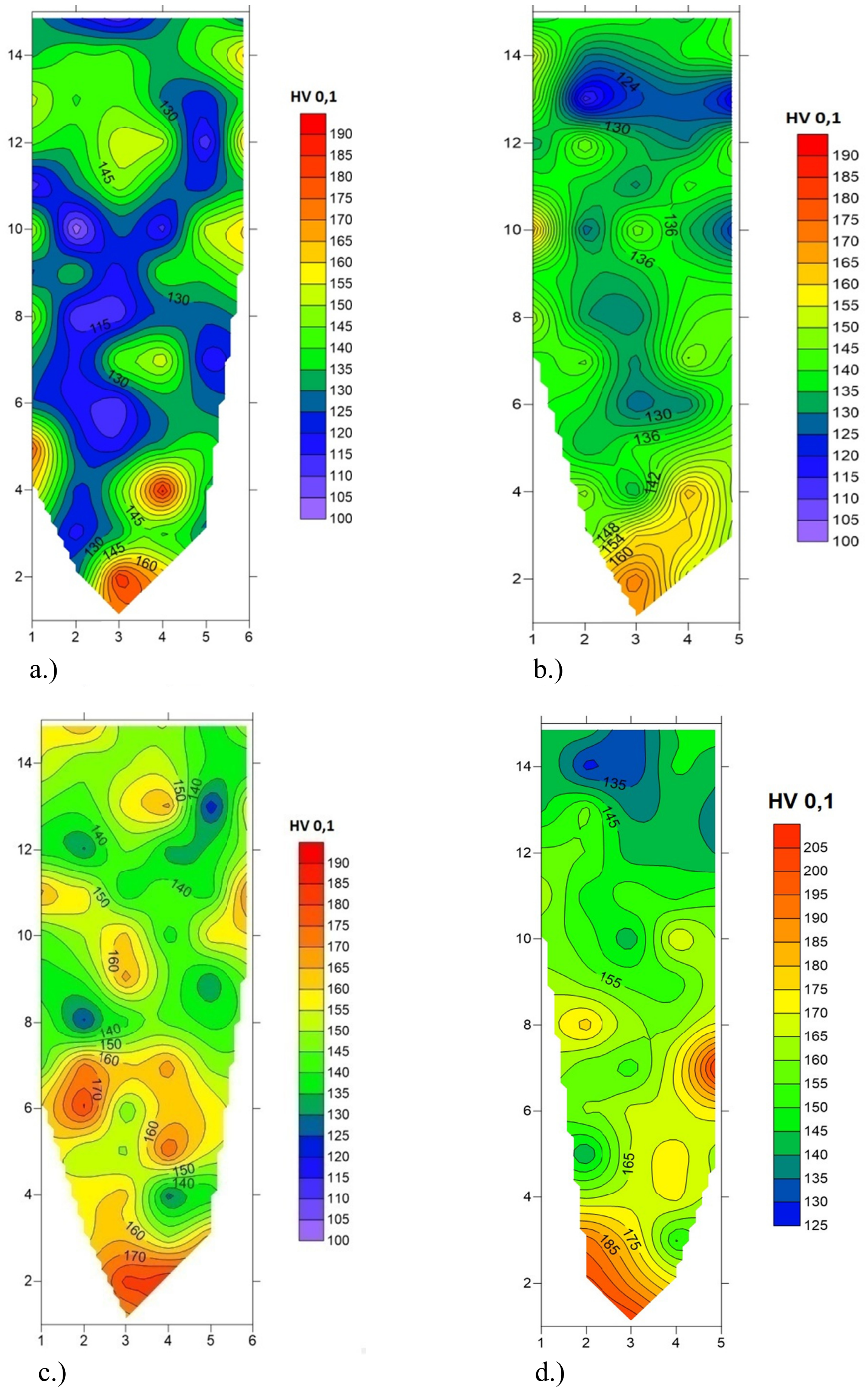

Fig. 6. Hardness distribution maps for IF steel after tensile test: a.) initial sample, b.) sample after first pass, c.) sample after fourth pass, d.) sample after eighth pass

tested steel. After fourth and eighth pass the reserve of plasticity YS/TS is 0.94. Steel in the initial state is characterized by good plastic properties. A_5 elongation reaches the value of 55% and necking (reduction of area) is at a level of 65%, however, with the increase of number of passes a sharp drop in ductility of the material was noticed. A_5 elongation of the material has dropped from 55% to 29% after the first pass and then it decreased with the increase of number of passes to value of 14% after the 4th pass and 10% after the 8th pass. The value Z of necking changes slightly with subsequent passes through the DRECE device. The highest value of necking falls to the lowest value of YS/TS ratio. Such behaviour of material after a SPD process is characteristic for most of the deep drawing low carbon steels. This phenomenon can be observed in materials deformed with the ECAP method but DRECE can be used for materials having bigger dimensions.

TABLE 2

Elongation, necking, tensile strength, yield stress and value of the reserve of plasticity of IF steel obtained in tensile test

Number of passes, α = 108°	**A_5, %**	**Z, %**	**TS**	**YS**	**YS/TS**
initial state	55	65	268	121	0.45
1×	29	60	296	276	0.93
4×	14	61	348	326	0.94
8×	10	58	338	319	0.94

In order to illustrate the changes of properties of the tested steel hardness measurements were taken with a semi-automatic method and then the results of those measurements were illustrated as hardness distribution maps for the sample in the initial state and after the first and fourth pass through DRECE (Fig. 6). The increase of hardness of the tested steel is noticeable after the first pass. At a distance of 6 mm from the spot of sample rupture the average value of HV0.1 for the initial sample is 120 and for the sample after the first pass is 132. The biggest strain hardening is present after the fourth pass through the DRECE device. In this case hardness HV0.1 of IF steel at the distance of 6 mm from the spot of sample rupture is 163. After consecutive passes through DRECE a slight increase in hardness is observed. After eighth pass hardness HV0.1 is 165.

Hardness in the area closest to fracture for the sample in the initial state and after the first pass is 160 HV0.1. A slightly higher hardness in this area has been observed for the material after the 4th pass through the DRECE (170 HV0.1). Hardness in the area closest to fracture for the sample after the eighth pass is 185 HV0.1. The hardness measurements carried out indicate the hardening of IF steel after the DRECE process.

4. Conclusions

The results show positive impact of the SPD process held by the DRECE technique on mechanical properties of tested steel. Both strength characteristics and hardness measurements confirm significant improvement of mechanical properties after the DRECE process in relation to the initial material. The highest value of tensile strength and yield stress is observed after the 4th pass. Tensile strength has increased by 30% in relation to the initial material and yield stress almost tripled. Further increasing the number of passes does not significant increase the mechanical properties. The value A_5 of elongation is reduced with the number of passes. After 8th passes elongation decreased from 55% to 10%. From this point of view it seems important to use a suitable heat treatment to improve the ductility of the material while maintaining high mechanical properties. The material had the highest hardness after 4th pass through the DRECE device. HV0.1 hardness increased by over 30% in relation to the initial material.

The increase of mechanical properties after the DRECE process is attributed to the changes occurring in the micro structure (grain subdivision to an ultra-fine-grained size) after SPD, which are the subject of further research and analysis.

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