University of Banja Luka
Faculty of Mechanical Engineering
DEMI 2017
13th International Conference on Accomplishments in Mechanical and Industrial Engineering

INFLUENCE OF PROCESS PARAMETERS ON THE FRICTION COEFFICIENT IN ONE AND MULTI PHASE STEEL STRIP DRAWING IRONING TEST

S. Aleksandrović [1], S. Đačić [2], M. Stefanović[3], M. Đorđević[4], V. Lazic[5], D. Arsic[6]

Summary: *Part of the experimental results of influence on friction in the stripe ironing process with double thinning are presented in this paper. Applied was Schlosser model for evaluating influence of lateral force, contact pressure, average absolute roughness height and thinning strain on friction coefficient. Applied was classical model because of sufficient intensity of drawing and lateral force. If a lateral and drawing forces are small, classical model is not suitable and give unreal negative friction coefficient values. 20 mm wide and 2.5 mm thick strips of mild steel DC04 sheets were used in the single, three and four-phase process with a maximum thinning deformation of about 29%. Appropriate lubricant, mineral oil, was used in conditions of lower speed of 20 mm/min. Three and four phase process was realized with variable lateral force of 5, 10, 15 and 20 kN. The applied experimental test procedure enables the precise quantification of lateral force, contact pressure, thinning strain and roughness influence on friction to be established. Test also enables evaluation of lubricants quality.*
Key words: strip ironing test, mild steel, friction coefficient

1. INTRODUCTION

Process of ironing is metal forming process which combine features of sheet metal forming and massive (bulk) forming. Thinnig strain reach over 25%, and contact pressure over 1000 MPa [1]. It is well known application of the ironing process in manufacturing different kinds of thin walled cans. World annual production (especially for beverage cans) are more than billion pieces. In the tribologycal sense, ironing process is one of the most severe, owing to the high surface expansion, large plastic strains and high normal pressure at the tool-workpiece interface. Considering previous notice more researchers still interested in ironing. During the last decade significant attention is paid on investigation of environmentally friendly lubricants application [1, 2, 3].

[1] Dr S. Aleksandrovic, prof., Faculty of Engineering, University of Kragujevac, Serbia, omdlab@kg.ac.rs
[2] Mr S. Djacic, Coal Mine, Pljevlja, Montenegro, djale@t-com.me
[3] Dr M. Stefanovic, prof. ret., Faculty of Engineering, University of Kragujevac, Serbia, stefan@kg.ac.rs
[4] M. Djordjevic, PhD student, Fac. of Techn. Sciences Kos. Mitrovica, Univ of Pristina, Serbia, tpolab@fink.rs
[5] Dr V. Lazic, prof., Faculty of Engineering, University of Kragujevac, Serbia, vlazic@kg.ac.rs
[6] D. Arsic, PhD student, Faculty of Engineering, University of Kragujevac, Serbia, cmz@fink.rs

Mostly in order to quantify the performance of the individual lubricants, a different experimental test methods has been developed. Wide applying have double (or single) sided thinning stripe ironing test in different variations [4, 5, 6, 7, 8]. Following mathematical model is mainly, so called Schlosser model [4]. Despite its evident deficiency or inaccuracy was indicated yet in article [5], and in [9] detailed motivated, however that model is applying even in recent extensive researches [8]. In authors investigations [9, 10, 11] proposed was different, or corrected mathematical model usable in all conditions with real results. In this paper presented is experimental investigation of process parameters (lateral force, thinning strain, nominal pressure, roughness) influence on friction coefficient in double sided ironing of DC04 steel sheet stripes. Applied was classical, less accurate but simpler Schlosser model because of convenient conditions.

2. EXPERIMENT

2.1 DEVICE DESCRIPTION, PHYSICAL AND MATHEMATICAL MODEL

The special device for physical modeling the symmetrical contact between the sheet strip and die was used for experimental investigation (Fig. 1 and Fig. 2). The sheet metal sample (strip 2) is placed in the jaws (1) vertically. In the initial phase the thinning makes such that the right-hand sliding tool element (6 right) acts upon the strip by lateral force F_D (Fig. 2). Due to the fixed left side tool element (6 left) and the action of right element, the even double sided ironing of the strip is realized.

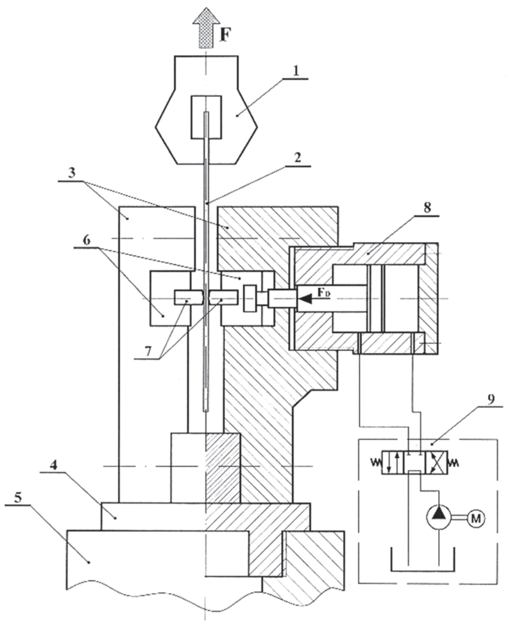

Fig. 1 *Experimental device scheme*

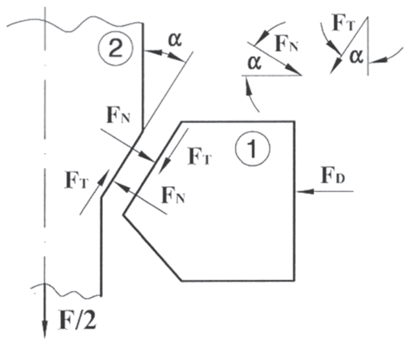

Fig. 2 *Force acting scheme*

After the initial thinning deformation was realized, the tensile force F begins to act, and the ironing process continues until the sample length is executed. The main action of the ERICHSEN 142/12 laboratory hydraulic press is used as the tensile force across the range of 0-20 kN at speed of 20 mm/min. The lateral force is realized by the hydro-cylinder (8, Fig. 1). The maximum range of the lateral force is 0-50 kN. The piston pushes right hand element (6) which is coupled to the sliding element (7). The hydro cylinder (8) is powered by the independent hydraulic aggregate (9), which contains the filter, electric motor, pump, two position directional control valve, adjustable control valve for lateral force and manometer. The data acquisition system measures drawing force dependence on the sliding length or time and the constant intensity of lateral force [10, 11, 12].

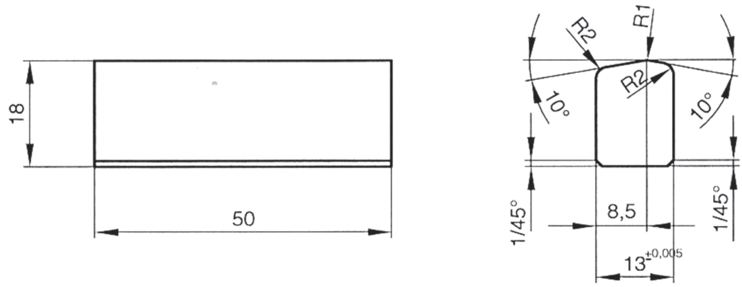

Fig. 3 *Tool elements geometry*

Geometry of the tool elements are shown at Fig. 3. Physical appearance of elements and assembly can be seen at Fig. 4.

For the contact elements material chosen was alloyed tool steel X160CrMoV12 with 62 HRC hardness after thermal treatment. Active surfaces are fine ground and polished with average absolute roughness height R_a≈0,06 μm.

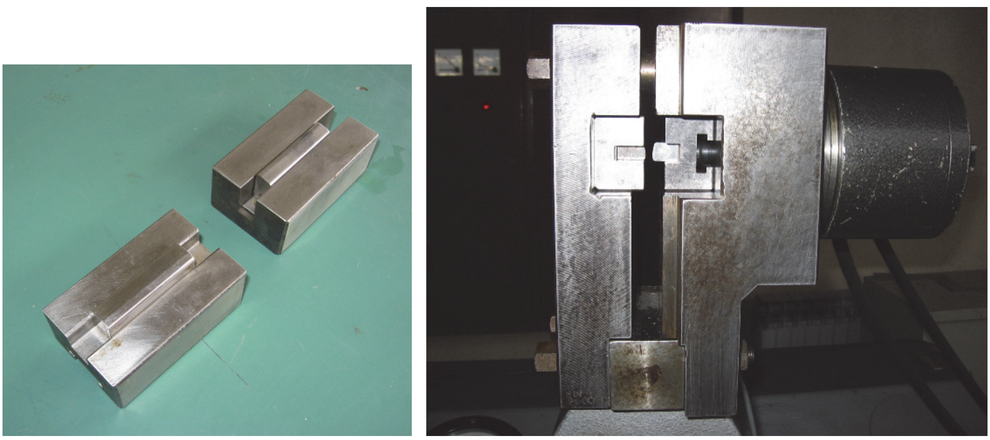

Fig. 4 *View of tool elements and tool assembly*

According to chosen model [4, 8, 10] following formulas for friction coefficient and average calculated (nominal) pressure was used:

$$\mu = \frac{\dfrac{F}{2F_D} - tg\alpha}{\dfrac{F}{2F_D} tg\alpha + 1} = \frac{F - 2F_D tg\alpha}{Ftg\alpha + 2F_D} \tag{1}$$

$$\overline{p} = \frac{F \sin^2 \alpha + F_D \sin 2\alpha}{b(s_0 - s_1)} \tag{2}$$

Formulas (1) and (2) with current data for this experiment, are:

$$\mu = \frac{F - 0.3526 \cdot F_D}{0{,}1763 \cdot F + 2 \cdot F_D} \tag{3}$$

$$\overline{p} = \frac{0.03015 \cdot F + 0{,}34202 \cdot F_D}{20.3(2.49 - s_1)} \tag{4}$$

2.2 STRIP MATERIAL PROPERTIES

Geometry of the strip is shown in Fig. 5 and Tab. 1.

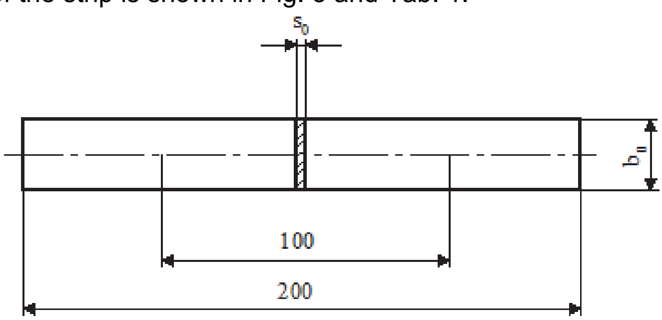

Fig. 5 *Strip geometry*

Table 1 Strip dimensions

Material		l_0 [mm]	b_0 [mm]	s_0 [mm]
Č 0148 (DC04)	min	100	20,2	2,47
	sred.	100	20,3	2,49

For experimental investigations in this paper chosen was the low carbon steel sheet DC04. Specimens for mechanical properties were prepared according to standards SRPS EN ISO 6892 - 1.2012. Determined material characteristics are shown in Tab. 2.

Table 2 *Mechanical properties*

Material		$R_{p0,2}$ [MPa]	R_M [MPa]	$R_{p0,2}/R_M$	A [%]	n
Č 0148 (DC04)	min	184,53	283,77	0,65	57,90	0,215
	sred.	185,16	284,54	0,65	57,95	0,216

In Tab. 2 $R_{p0.2}$ is yield strength, R_M is tensile strength, A is percenage elongation at moment of fracture and "n" is strain hardening exponent.

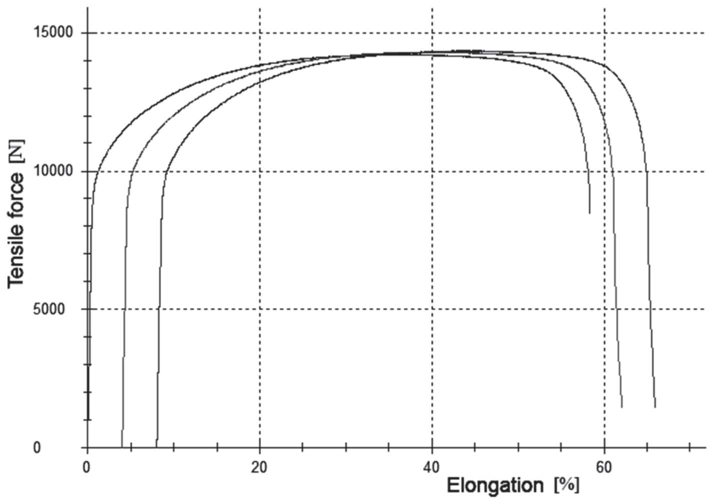

Fig. 6 *Tensile force - strain curves*

Experimental tensile force – strain curves (Fig. 6) were obtained for three specimens with excellent repeatability. As can be seen, force curves have smooth dependence on strain which is common for such a material.

3. RESULTS AND DISCUSSION

Within results of this experiment, diagrams of tensile forces are presented first (Fig. 7, Fig. 8, Fig. 9 and Fig. 10). In the first case (Fig. 7) used are one phase process. Each stripe sliding process needs separate specimen with appropriate lateral force (F_D). Values are chosen according to empirical recommendation (5kN; 10 kN and 15 kN). Lateral force of 15 kN is below the limiting intensity and process reached full sliding length of about 60 mm.

Fig. 8 represents severe conditions. There is three phase process realized on the single specimen. First sliding is performed with lateral force of 5 kN at the path length of about 56 mm. Second phase is performed on the same specimen but ironing starts 21 mm after stripe path beginning. Lateral force was higher: 10 kN. Third sliding passage take place on the same strip also, after 37 mm path. Conditions was severe but no brake occured.

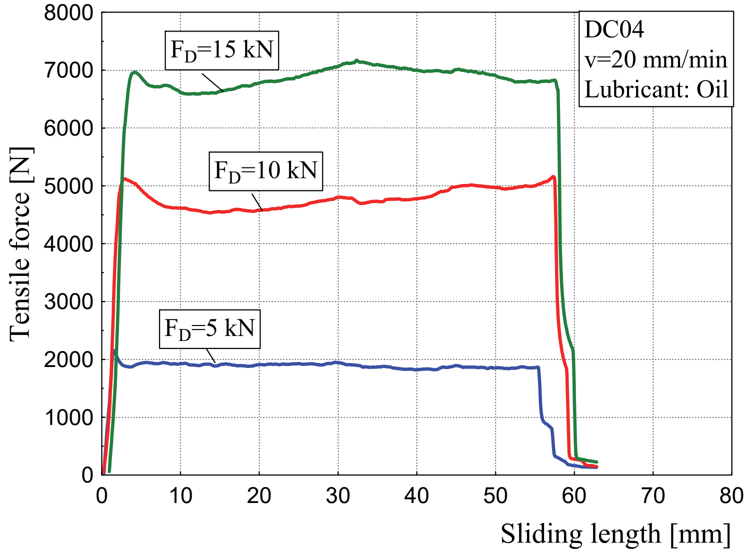

Fig. 7 *Tensile force vs sliding length curves*

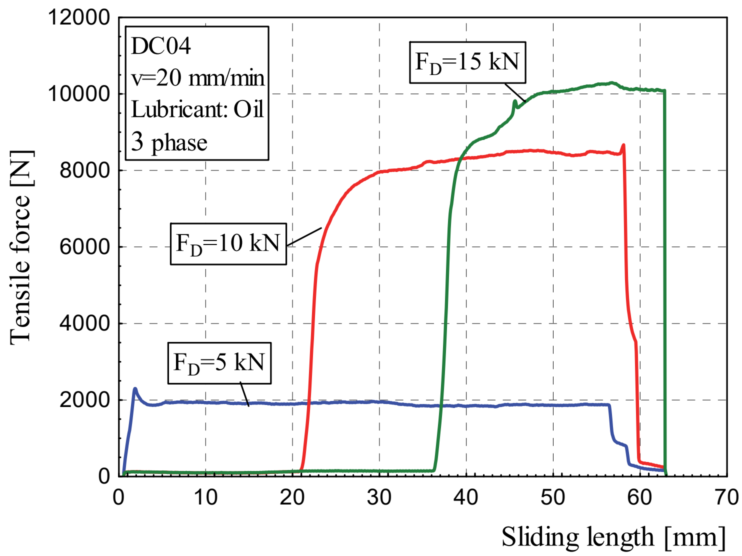

Fig. 8 *Tensile force vs sliding length curves*

Lubricant in the process was mineral oil (signed PRESS 509 EP) of domestic producer, intended to drawing operations. Kinematic viscosity of that lubricant is 170 mm^2/s at 40 °C, and density of 0.950 g/cm^3 at 20 °C.

Fig. 9 shows tensile force diagrams for four phase ironing process with constant lateral force of 5 kN in each phase. Second, third and four phase starts with about 14 mm offset like in previous case. Sliding process is relatively smooth and no brake occurs.

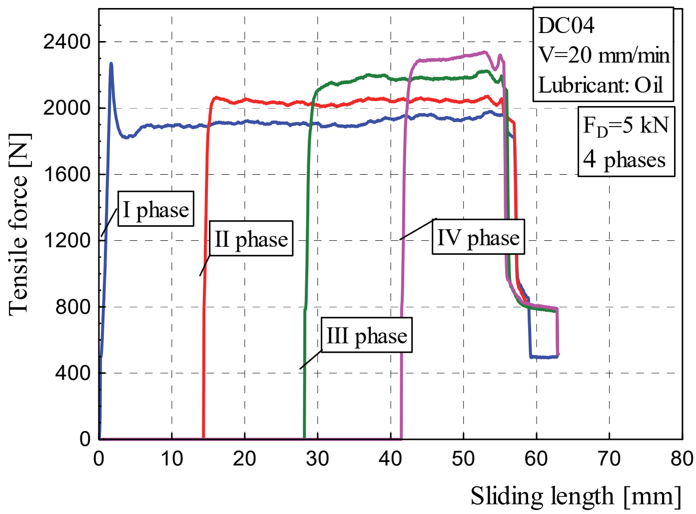

Fig. 9 *Tensile force vs sliding length curves*

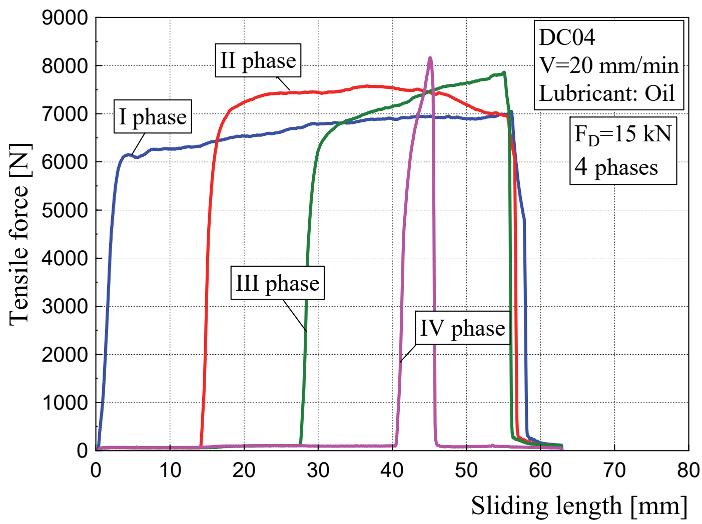

Fig. 10 *Tensile force vs sliding length curves*

Fig. 10 shows tensile force diagrams for four phase ironing process with constant lateral force of 15 kN in each phase. Conditions are more severe. Second, third and four phase starts with about 14 mm offset like in previous case. Sliding process is relatively stable from first to third phase and no brake occurs, but in fourth phase brake happend after only 6 mm of sliding length.

Fig. 11 *Strips after multi phase ironing*

In this study investigated are the influences of lateral force, calculated (nominal) pressure, thinning strain and average roughness on the friction coefficient (Fig. 12, 13, 14 and 15).

Dependences given at the. Fig. 12 determined are according to terms (1) and (3). For tensile force F intensities was adopted average values. For one phase process friction coefficient (μ) have relatively small values, even in case of 15 kN lateral force.

Diagrams for three phase processes clearly shows that μ increase, and it is in accordance with heavier process conditions. Especially in the three phase process with lateral force increasing (Fig. 12), μ reached maximum value.

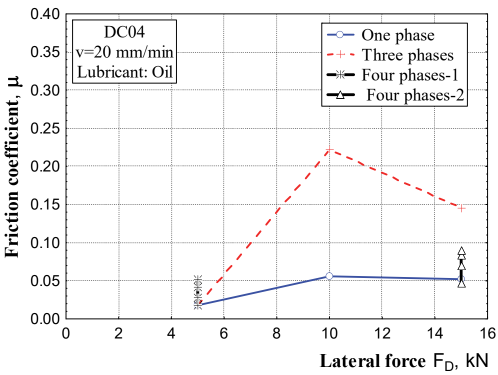

Fig. 12 *Friction coefficient dependence on lateral force*

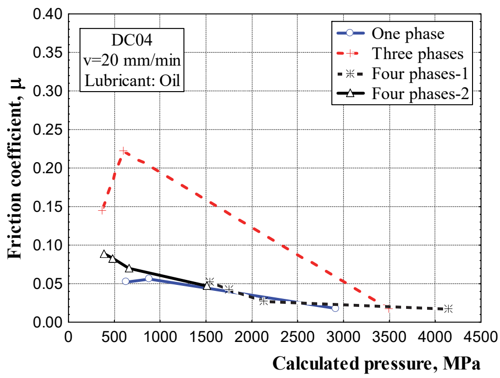

Fig. 13 *Friction coefficient dependence on calculated pressure*

Fig. 13 shows friction coefficient dependence on calculated pressure according to terms (2) and (4). For that parameter must be noticed that it is only calculated or nominal parameter, which inversely depends on strip thinning strain (Fig. 14). Because of that, pressure values are reached unreal intensities for very small thinning. So, calculated pressure need to be considered like parameter related to thinning strain, rather than real pressure.

For diagrams at Fig. 13 need to be notice that the process starts at the high calculated pressure values and goes to lower values (from right to left side of diagram). As can be seen from Fig. 13 and Fig. 14, friction coefficient increasing with thinning strain increasing, or calculated pressure decreasing.

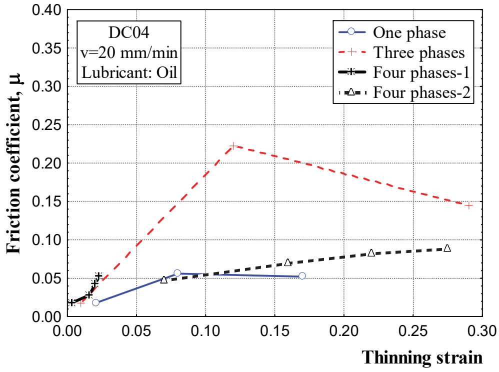

Fig. 14 *Friction coefficient dependence on thinning strain*

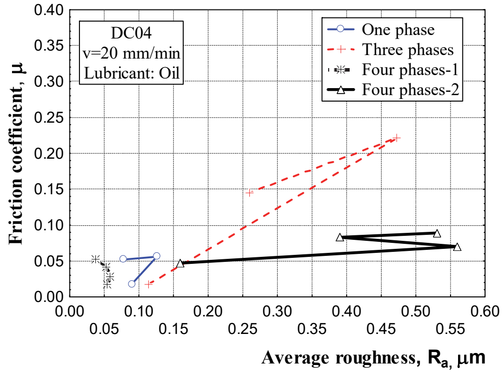

Fig. 15 *Friction coefficient vs average roughness*

Relation between friction coefficient and average roughness R_a (Fig. 15) gives somewhat unexpected values in four phase (process 2) cases. In third stage μ slightly increases while R_a decreases. Expectation is opposite. Possible explanation is in the way of μ calculation and R_a determination. μ is calculated according to formulas (2 and 4) and depends only of tensile force F and lateral force F_D . In other side R_a is determined experimentally, by measuring.

Also, it is possible to occur polishing effect in the all cases (except in four phase-1 process with low lateral force intensity) with deceasing R_a and the calculated lower μ values at the same time.

4. CONCLUSIONS

Experimental analysis was accomplished in this study. Intention was to evaluate process parameters influence on the friction coefficient. Results shows the following annotations:

a) increasing of lateral and drawing forces both in three phase process strongly influence on friction coefficient increasing,

b) thinning strain increasing, i.e. calculated (nominal) pressure decreasing, caused friction coefficient increasing,

c) known relationship of average roughness R_a on friction coefficient is confirmed, but polishing effect occurred in the some stages of processes where R_a and friction coefficient decreasing.

For further evaluations of different influences on the steel ironing process (especially multi phase) needs to continue extensive experiments in different conditions.

ACKNOWLEDGEMENT

The work reported in this paper was partially supported by the Serbian Ministry of Education, Science and Technological development, through contract TR34002.

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