# Statistical S For Strengths Of Joining PA Sheets Welded By Friction Stir Welding Process

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## Abstract

In this research, a study of strengths for PA (Nylon 6,6) sheets welded by FSW process is analyzed by Minitab-16 program. For this purpose a commercial PA sheets provided with dimension of 250× 150× 8 mm were used. An especial tool was designed with 16 mm diameter for the shoulder, while pin length and diameter were 7.8 and 4 mm respectively. The rotation speeds used were (2000, 1570, 1255, 994, and 780) rpm, and traverse speeds were (27, 42, and 62) mm/min. tensile and impact tests were done in order to evaluate mechanical behavior of material. For analysis the effect of the variables on strength of the joint, software program (Minitab 16) used to design plan for joint and show the effects of the variables by analysis them. It was found that welding strength increases with increasing rotational speed and decreases with traverse speed increase and the optimum properties were obtained when these speeds were 1570 rpm and 42 mm/min respectively.

**Keyword:** Friction Stir Welding (FSW) process, Polyamide (PA) sheets, Special tool, Mechanical properties (Tensile & Impact), Design Of Experimental (DOE).

## 1- Introduction

The automotive industry is on the brink of a revolution, and the plastics industry poised to play a major role. The real plastics revolution in automotive industry began in 1950 when thermoplastics made their debut, starting with ABS and going on to polyamide, polyacetal and polycarbonate together with introduction of alloys and blends of various polymers. The ongoing development of advanced and high-performance polymers has dramatically increased their usage. Originally plastics were specified because they offered good mechanical properties combined with excellent appearance, including the possibility of self-coloring. The application of plastic components in the automotive industry has been increasing over the last decades. Nowadays, the plastics are used mainly to make cars more energy efficient by reducing weight, together with providing durability, corrosion resistance, toughness, design flexibility, resiliency and high performance at low cost [1]. Friction stir welding is a new solid-state joining technique, which was originally developed and successfully applied for aluminum alloys. However, recently, attempts have been made to adapt friction stir welding technology to the joining of thermoplastic materials. In this solid-state joining process which welds the materials whose characteristics and properties must remain unchanged as far as possible [2]. Many researchers investigated and formulated friction stir welding process which has produced structural joints superior to conventional arc welds in Aluminum, Steel, Nickel, Copper and Titanium alloy. Research and development efforts over the last decade have resulted in improvements in friction stir welding and the spin-off of a series of related technologies.

S. Saeedy [3] had studied feasibility of friction stir welding on medium density polyethylene blanks. The optimum welding condition has been determined. It had been demonstrated that rotation speed and tool tilt angle have key roles in the seam elongation and strength respectively. By applying this method of welding on polyethylene blanks, strength of 70% of the base material was achieved.

S Saeedy [4] studied the effect that varying process parameters (rotational speed, welding speed, and attack angle) had on the weld quality of polyethylene sheets. A strength value of 75 % of that of the base material was achieved.

Mustafa Aydin [5] investigated the weld ability of polyethylene via friction stir welding method. In this study, three different heating processes were used. These processes are welding at room temperature, welding by preheating plate samples at 50°C and 80°C with metal molding. In the experiments, a tensile strength of 72% was achieved in non-preheated welds whereas tensile strength of parent material was achieved approximately at an optimum value of 89% by pre-heating at 50°C.

Erica Anna Squeo [6] performed friction stir welding of 3 mm thick Polyethylene sheets with a cylindrical steel pin with two pin diameters. Author has concluded that even if process optimization is required, the final performances of the joints are sufficient to assess that friction stir welding of polyethylene may be a valid alternative to conventional joining technologies.

The aim of this study was to analysis the role of FSW parameters (Rotation and Traverse speeds) on the mechanical strengths (Tensile and Impact) of the joints, in this research, PA sheets were welded in butt joint by cylindrical tool.

## 2- Experimental Work:

### **2.1** - Materials and Tool design:

In the present work, the commercial polyamide sheets (nylon 6,6) with 8 mm thickness were utilized and samples were cut in 150×250 mm size, to create a but joint weld, with characteristics of 15.57 MP tensile strength, 36.636 KJ/m impact strength, and 265.8˚C melting point. FSW was performed on Nylon 6,6 material samples that were held using a specially designed clamping fixture which was fixed onto a vertical milling machine. The pin type tool made of mild steel with a nominal diameter of pin and shoulder of 4mm and 16mm respectively, and also pin length of 7.8mm was used in the present investigation. Fig. 1.

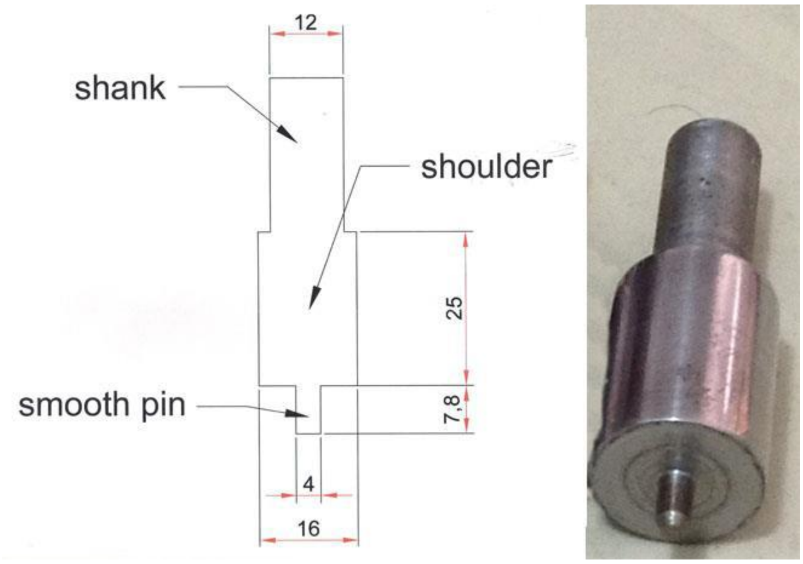


Fig. 1. The tool shape

**2.2- Process Preparation:**

Rotation speed of the pin and traverse speed of the tool along the weld line at the beginning of the welding procedure was considered as the processing parameters and from the preliminary experimental results, the rotation speed was (780, 994, 1255, 1570, 2000) rpm and traverse speed was (27, 42, 62) mm/min.

In order to determine mechanical properties, the resulting test specimens were tested with a tensile test and Izod impact test machines. A general full-factorial DOE was designed to explore effects of operating parameters and ANOVA study was performed in order to determine the significance of process parameters and the relationship between them and the mechanical properties of the welds.

Initially the FSW tool was plunged into the work material until it touched the shoulder surface and few seconds were given as dwelling time for preheating and softening of the material, and the tool moves along the weld line. The tool was removed when it reached the end of the line and a hole was thus created at the end of the joint interface, as shown in fig.2 [7].

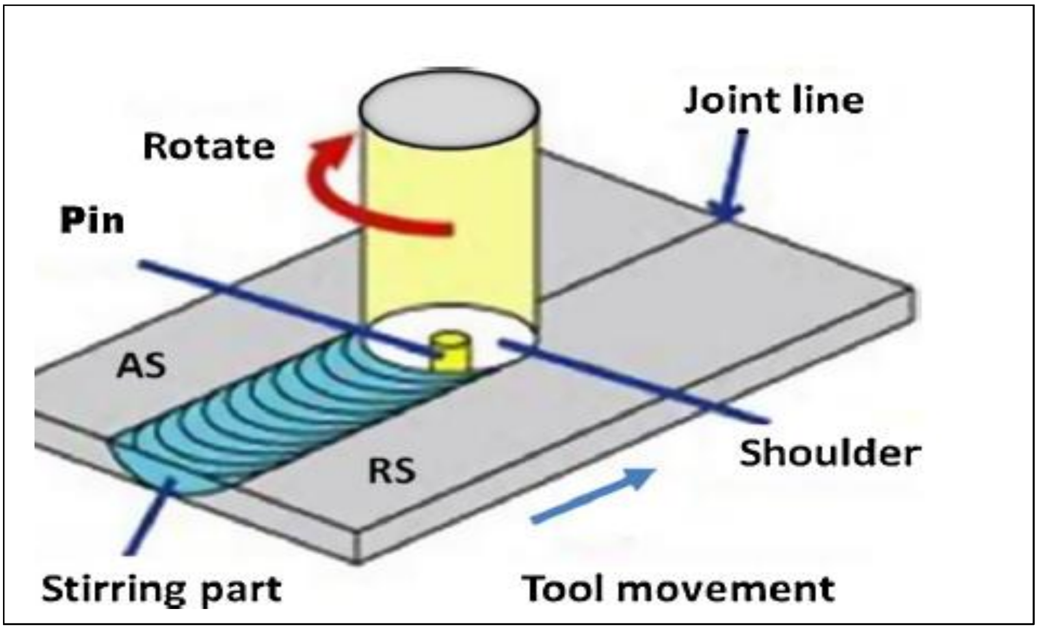


Fig. 2- Schematic of friction stir welding process [7]

The specimen of tensile and impact tests were cut from the middle portion of the welded plates. The cutting direction is also perpendicular to the welding direction, as shown in Fig. 3 and 4.

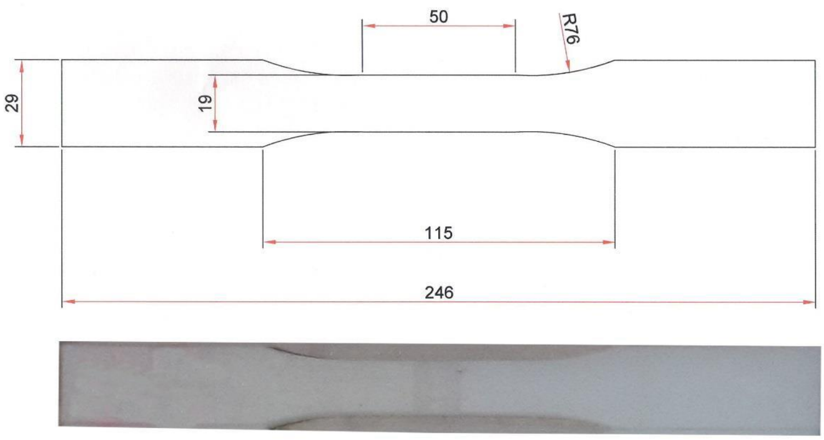


Fig.3 the tensile test specimens of Polyamide according ASTM-D 638-99 all dimension in mm [8]

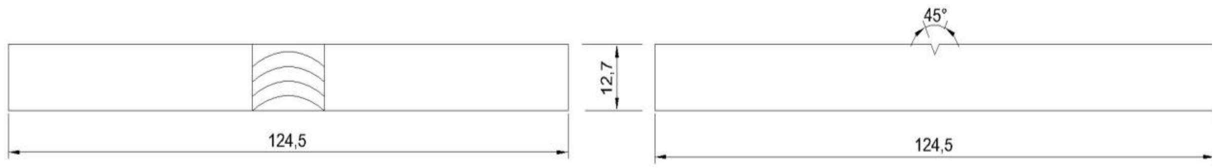


Fig. 4 the impact test specimens of polyamide for base material (notched) and welded sheets (un-notched) according ASTM standard D-6110-02 all dimension in mm [9]

These specimens were formed using a CNC milling machine to a standard size according to ASTM D 638-99 for tensile test [8], and for impact test ASTM D-6110-02 [9] for welded parts and base material respectively. Tensile strength tests were conducted in a Zwick machine, the cross head speed of testing machine was 5 mm/min, and the load and displacement were simultaneously recorded during test. Impact strength tests were conducted in a SBN machine in Uremia University, the head of pendulum weight was 2.036 Kg and the distance of the arm was 39.48Cm.

**3- Result and discussion:**

In the experimental procedure , it was found that rotation speed smaller than 780 rpm , low frictional heat and inadequate material mixing results in a very low mechanical strength of welds , as it is observed the welds of this condition could be easily fracture by hands. Results also showed that in traverse speed larger than 62mm/min, weld line area is full of deformation and external voids leading to poor weld quality. On other hand, the limitation of the vertical milling machine restrict using rotation speed more than 2000 rpm and traverse speed smaller than 27 mm/min. Fig. 5 shows the low rotation speed with high traverse speed result very poor joint and had many external voids and no weld part.

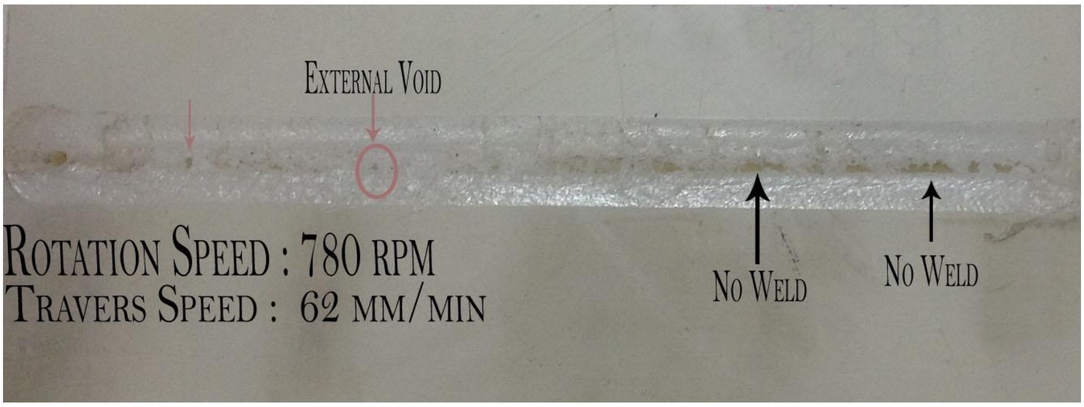


Fig. 5 the weld line and defects at high traverse speed and low rotation speed

### 3.1- Effect of processing parameters on tensile strength

Fig. 6 shows the results of tensile tests. The maximum relative tensile strength (about 54.61% of the base material) occurred in a specimen welded by 1570 rpm rotation speed and 42 mm/min, while the minimum (about 18.53% of the base material) occurred in a sample welded by 1255 rpm rotation speed and 62mm/min traverse speed. Low spindle speeds lead to insufficient flow of the material in the weld zone and lack of fusion between the weld and the base material. The stirring of the pin increases with the tool rotation speed, friction speed also increases with the rotation [10].

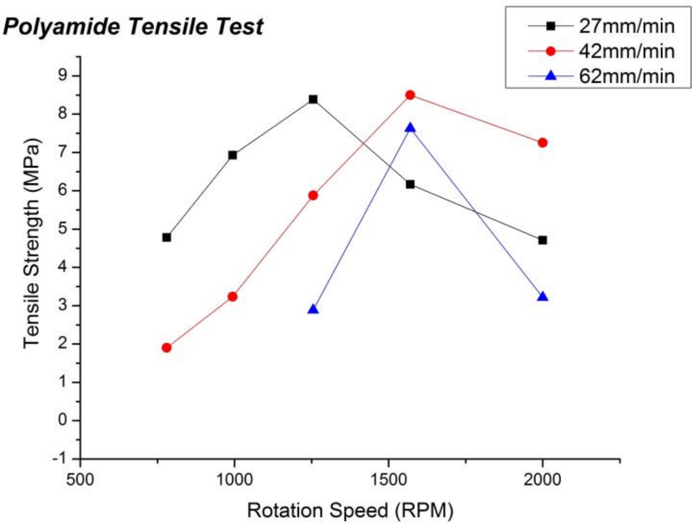


Fig. 6 the tensile strength results

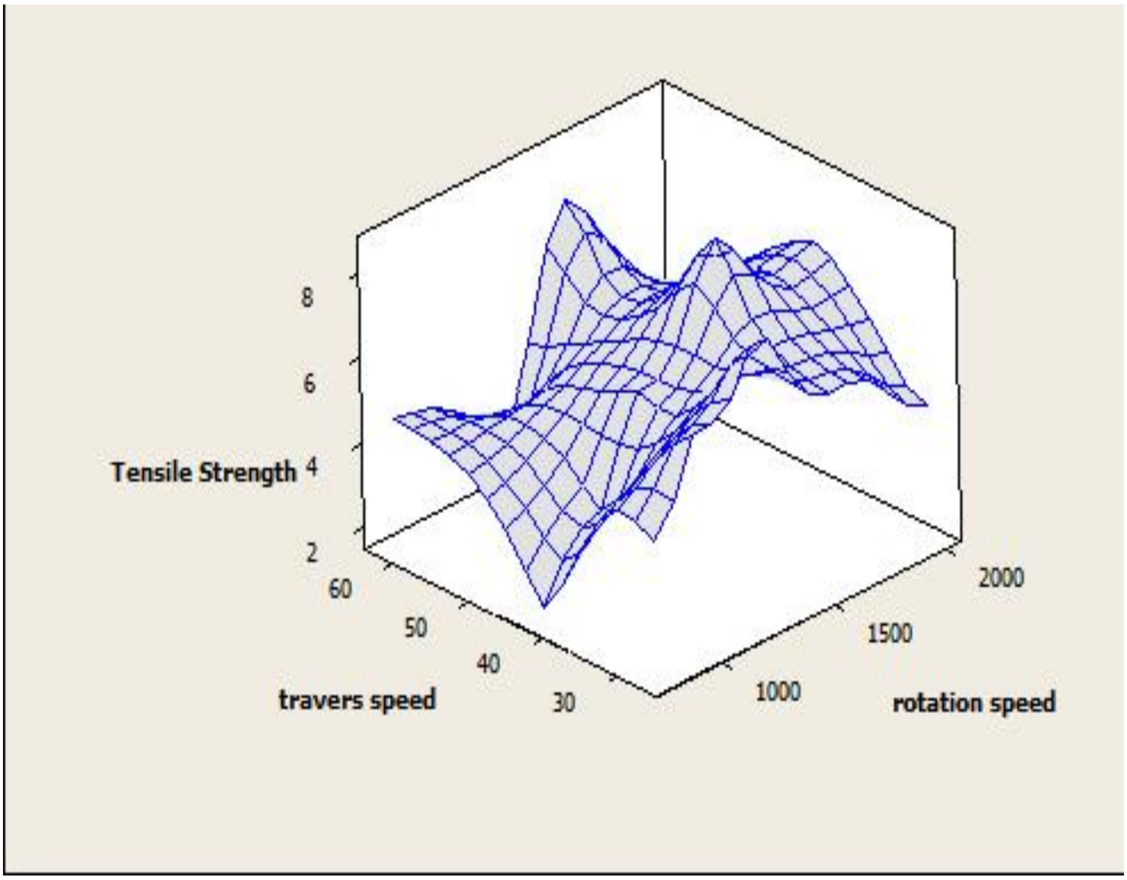


Fig. 7 the effect of rotation and traverse speed on tensile strength

Fig. 7 shows that the tensile strength increases with increase the rotation speed until reach to the 1570rpm, and after this a reduction in tensile strength appeared on the results, that means, welding in excessive rotation speed (more than 1570 rpm) will loss more particle from the base material leads to decrease in thickness, in addition, with excessive rotation speed the base material burn and produce large difficult of crystalline among the stir zones and seam weld, that put the weld in an uncontrolled situation. Also shows that, high traverse speed reduction the tensile strength and lead to poor mixing of the material. When the traverse speed increase from 27 to 62 mm/min the tensile strength decrease, that means, when the traverse speed in small number that allows the two sheets to get enough time for mixing and homogenization. Weld line deflection and deformation in samples with high traverse speed lead to poor material mixing and thus weak tensile strength.

### 3.2 Effect of process parameters on impact strength:

Fig. 8 shows the results of impact strength for polyamide, the maximum relative impact strength (about 29.5% of the base material) was obtained in a specimen welded by 1570rpm rotation speed and 42mm/min traverse speed, like in tensile strength. Moreover, the minimum strength (about 9.6% of the base material) was occurred in a sample welded by 780rpm rotation speed and 42mm/min traverse speed, the effect of rotation speed and traverse speed analyzed by the Minitab-16 program (ANOVA), as shown in fig. 9. When rotation speed increases the impact strength increase until reach to the optimum (1570rpm) and then the impact strength decrease, while when the traverse speed increase the impact strength decrease, it can be explained by the fact that in case of slower traverse speed the tool has more time to mix and heat up the material, and higher rotation speed also results in higher heating effect.

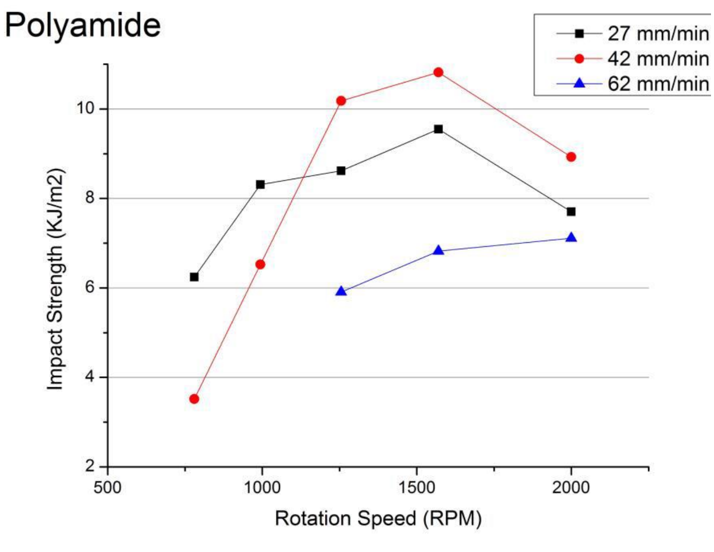


Fig. 8 the impact strength results

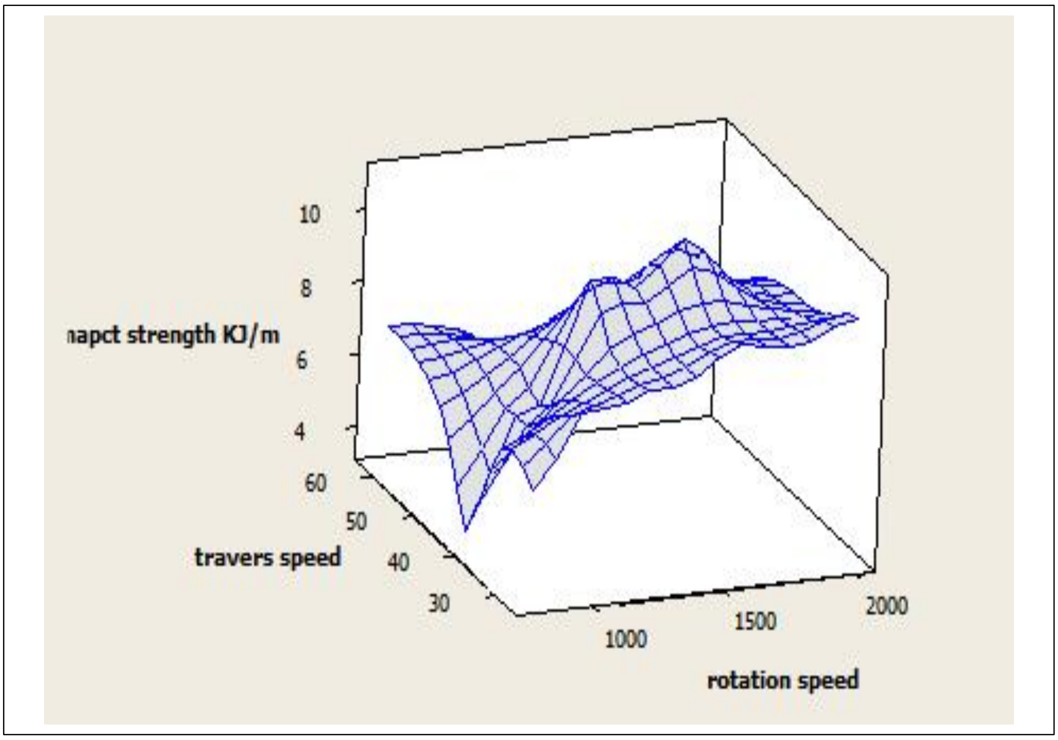


Fig.9 the effect of rotation and traverse speed on impact strength

## 4. Conclusions

In this paper friction stir welding process is used to weld polyamide (nylon 6,6) sheets. As a mechanical properties, tensile and impact strength of friction stir welded polyamide sheets was studied. It appears that welding strength increase when the rotation speed increase until reach to the optimum and then decrease. Regarding the traverse speed, welding strength decrease when the traverse speed increase. The optimum condition was occurred when 1570rpm rotation speed at 42mm/min traverse speed was used. The tensile strength of the optimum was 8.5 MPa while the tensile strength of the base material was 15.57 MPa that means the relative strength of the joint was approximately 56% from the base material. Impact strength of the base material was 36.6 KJ/m2 while for the optimum condition result was 10.8 KJ/m2, its show the relative strength was approximately 30% from the base material.

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