An Investigation of Tube Spinning Using Ballizing Technique

M. H. Kassar, S. Z. El-Abden, M. N. El-Sheikh

Abstract: Thin-walled cup is considered as main parts in the development of aeronautic, aerospace, rocket capsule components, military industry, and other manufacturing process for daily use parts. These parts can be produced by conventional spinning with rollers or by ball spinning process. Recent development of ball spinning of tubes and thin wall thickness cup face challenge of large, consumed load due to material built up formation in front of the forming balls, this problem have been addressed separately in the literature without a unified approach to simultaneously overcome it. The current study introduces a new ball set design that is claimed to be able to overcome the pile-up problem simultaneously using a new forming tool based on ball spinning process or it can be called Ballizing technique. The new proposed design is built and verified. The proposed design consists of 4 balls distributed in four planes, having one ball in each plane. The first plane is set to suppress the pile-up formation, the second, third and fourth plane are set for the main forming process. Each two consecutive planes are shifted by 90 deg. from each other to suppress the folding creation. The results show that the new design has shown the potential to significantly overcome the pile-up formation in front of the forming balls beside its ability to complete the process with less forming force. The optimum rotational speed of the mandrel with the optimum feed rate of tool regarding the process load were determined.

Keywords: Tube spinning, Conventional spinning, Ball spinning, pile-up, thin wall thickness cup.

1. INTRODUCTION

Ball spinning is an innovative technique invented at the last three decades for manufacturing thin-walled tube with high precision and high mechanical properties [1]. The main advantages of the metal spinning process are low tooling costs, reduce forming loads, flexibility and near net shape production for various geometrical configurations therefore requiring less process development time and cost for customized products as compared to alternative processes [2]. The different axial symmetrical parts can be obtained by ball spinning. The working parts are divided to symmetrical, conical with curved drawing and combined parts. The spinning process doesn't enable to produce of unsymmetrical parts [3]. Tool design that are used for spinning processing is very simple, that secure lower cost and longer the time of exploitation life. The same tools can be used for individual operations at the different parts producing [4]. Flow forming is a cold metal forming process for the manufacture of rotationally symmetrical, hollow components, which indicates the process of reducing the thickness of the pipe wall or the cup wall [5]. Recently, tube spinning using balls has been extensively utilized in producing internally-spline sleeves or tubular components such as components with longitudinal or helical internal gear teeth, internal grooves, or internal ribs [6]. Previous studies on spinning were performed to test the effect of process parameters on the flow forming either by roller or by balls; some of these studies have been discussed here. Rotarescu, indicated that the final product of tube spinning process-using balls is mainly affected by; forming ball diameter, thickness reduction per pass, and formed tube ductility [7]. Also, Palmieri, concluded that material strength has a direct effect on, feed speed and the angular speed of the rotating part [8]. Plewiński And Drenger, showed that flow forming technologies significantly extend the possibilities of plastic forming of hard-to-deform materials. Incremental forming, due to smaller friction resistance, makes it possible to obtain larger deformations as compared to the traditional technologies [9]. Music et al, investigated the range of diameter and thickness that spinning process can perform and indicated that spinning process is capable of forming components of diameter ranging from 3 mm to 10 m, and thicknesses from 0.4 to 25 mm [10]. Kemin, et al, studied the ball spinning process performed by many balls distributed on the circumference of the workpiece and they found that; Ball spinning belongs to tube spinning by using balls as deformation tool instead of traditional method. As a new plastic forming process, ball spinning plays a remarkable role in forming of thin-walled tubular parts by reducing the wall thickness of tubular blank. The ball spinning process is characterized by its fairly small deformation zone as well as its relatively small spinning force. Furthermore, the stress of deformation zone in the ball spinning process is so high as to be subject to yield criterion. On the other hand, balls are distributed so uniformly along the circumference of deformation zone that the circumferential flow of metal in the deformation zone is confined and radial forces have balanced each other. Therefore, extremely thin-walled tubular parts with high dimension accuracy and good surface finish can be fabricated by means of the ball spinning process. However, the continuity and localization of plastic deformation in the ball spinning process leads to the complexity of its deformation mechanism [11]. Shuyong and Zhengyi, analyzed the ball spinning process mechanics in the manufacturing of thin wall cups, indicated that during ball spinning of the thin-walled tubular part, the spinning force F between the ball and the part can be divided into the three spinning force components, namely the radial force component F_r, the axial force component F_a and the tangential force component F_t. The calculation of the three

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spinning force components is essential to understanding the deformation law of ball spinning of the thin-walled tubular part [1]. Ahmed, suggested a new design of forming tool depending on 4 balls that able to decrease Simultaneously the built-up formation, this study focuses on the mechanics of tube thickness reduction exploring the forming loads, stresses, and strains. Ahmed found that the new suggested design of the forming tool may achieve the ability of preventing the pile-up formation in front of the forming tool [12]. Abd-Eltwab, et al, used the ballizing technique in the manufacturing of a tube with inner ribs by means of four balls in the same plane. Abd-Eltwab, et al, indicated the abilities of this technique and the optimum rotation speed and feed rate, which must be used with this process. They also indicated that, it can be used in smoothing surfaces by means of simple tooling [13]. Abd-Eltwab agreed with Ahmed and Thiruvarudchelvan in that the tangential force component is generally small and can be neglected in the process of ball spinning by balls distributed on the circumference of the workpiece [12,13,14]. The previous mentioned studies tried to investigate the ball spinning process and its parameters. However, the pile-up formation in front of the forming balls was only studied by Ahmed (Ahmed 2011) theoretically. The aim of this research is to investigate the ability of design and manufacture a spinning tool using balls that has the ability of modifying the balls planes and balls forming depth to be in different planes and distribute the thickness reduction on the different balls. Also, check the process parameters such as; rotational speed, feed rate, balls planes distances, and the amount of reduction in thickness distributed on each ball.

2. EXPERIMENTAL WORK

The thin wall cup was produced by the forming process in two stages as shown in Figure (1). A schematic for the conventional spinning process to form first stage of cup is shown in Figure (2.a) while a schematic for proposed rotary Ballizing process to form final wall thickness cup is shown in Figure (2.b). The general arrangement of experimental set-up used is shown in Figure (3). Commercial Aluminum specimens were prepared to be used in the program of experiments. The dimension of the required blank is 100 mm outer diameter, with thickness (t) 4 mm. Aluminum sheet was received and cut to make the blanks by laser machine (TRUMPF TCL4030). The rotating mandrel was clamped to the lathe chuck at one end and the workpiece (blank) mounted on the other end. The rollers were adjusted to produce the cup from the blank in first stage. In the second stage of the forming process the 4-adjusting screw of the forming device is turned until the forming balls slightly contact the outer surface of mandrel then move the forming balls back by the amount decided for the cup new thickness then the cup was mounted on the mandrel. The machine speeds and feeds were chosen for this particular operation as shown in Table (1). The feed was operated automatically. Consequently, the specimen rotates and forming balls move self-rotating and axially along its surface.

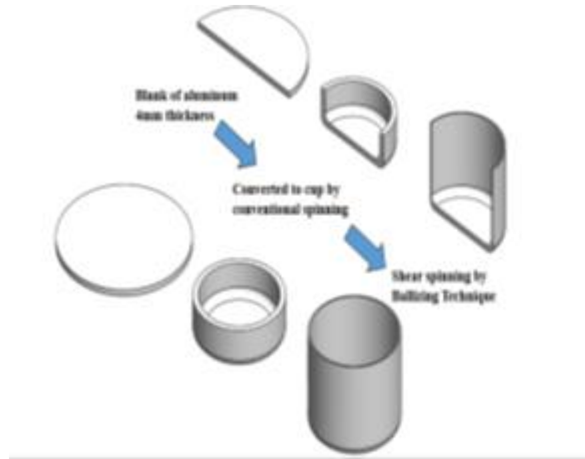


Fig. 1 *The two stages to form the thin wall thickness cup.*

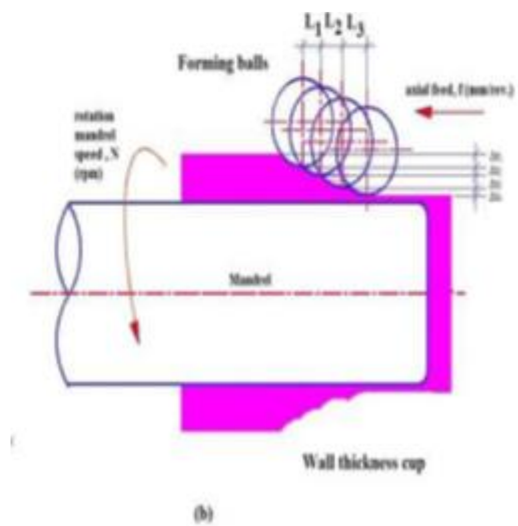


Fig.2 *(b) Schematic for the forming ball planes.*

The forming loads were measured by the dynamometer connected with data logger device through a transducer. Two sets of experiments have been performed, in the first set the effect of the parameters (Δt, f, N) on the formation loads were investigated. Four forming balls lie in the same plane. In second set of experiments, the influence of the position of forming balls on the thin wall cup product quality

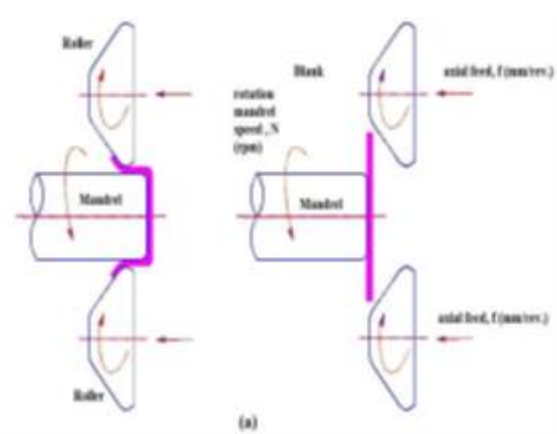
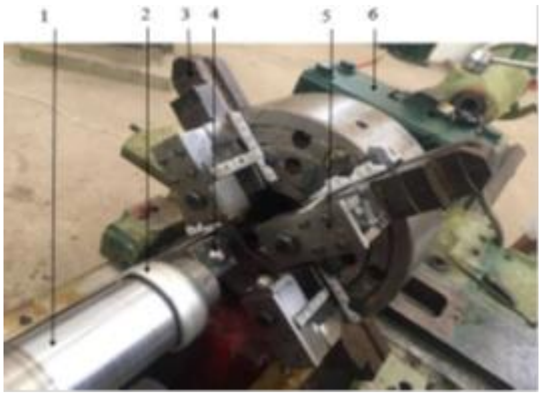


Fig. 2 *(a) Schematic for conventional spinning process to form first stage of cup.*



1	Mandrel	4	Ball
2	Cup	5	House of ball
3	Jaw	6	Dynamometer

Fig. 3 *Experimental set-up of the rotary Ballizing.*

was investigated as well as pile up of accumulated metal on front of forming balls. The values of selected parameters in first sets of experiments are shown in Table (1), while in the second set of experiments divided into three groups as shown in Table (2). All experiments in second sets were formed at mandrel rotational speed (150 rpm) and axial feed (0.3 mm/rev.) but the distance between the ball's plans (L1, L2 and L3 mm) are selected as shown in Table (2).

Table 1 *Experiments plan and operating conditions of the first sets of expriments.*

Investigation parameters	The value
Mandrel rotational speed, N	76, 150, 230 and 305 rpm
Axial feed, f	0.3, 0.6 and 0.91mm/rev.
Distance between the ball's plans (L1, L2 and L3 mm)	Zero (four balls lie in same plan)

Table 2 *Experiments plan and operating conditions of the other sets of expriments.*

Sample name \ Selected parameters		Δt_1 (mm)	Δt_2 (mm)	Δt_3 (mm)	Δt_4 (mm)	L_1 (mm)	L_2 (mm)	L_3 (mm)
Group (1)	**S1**	0.75	0.75	0.75	0.75	8	8	8
	S2	0.75	0.75	0.75	0.75	12	8	4
	S3	0.75	0.75	0.75	0.75	4	8	12
	S4	0.75	0.75	0.75	0.75	4	4	4
	S5	0.75	0.75	0.75	0.75	3	3	3
	S6	0.75	0.75	0.75	0.75	2	2	2
Group (2)	**S7**	0.3	0.6	0.9	1.2	2	2	2
	S8	0.3	0.6	0.9	1.2	1.75	1.75	1.75
	S9	0.3	0.6	0.9	1.2	1.5	1.5	1.5
	S10	0.3	0.6	0.9	1.2	1.66	1.66	1.66
	S11	0.3	0.6	0.9	1.2	1	1	1
	S12	0.3	0.6	0.9	1.2	0.5	0.5	0.5
Group (3)	**S13**	0.75	0.75	0.75	0.75	0.5	0.5	0.5
	S14	0.75	0.75	0.75	0.75	1	1	1
	S15	0.75	0.75	0.75	0.75	1.5	1.5	1.5
	S16	0.75	0.75	0.75	0.75	1.66	1.66	1.66
	S17	0.75	0.75	0.75	0.75	1.75	1.75	1.75
	S18	0.75	0.75	0.75	0.75	2	2	2

3 - EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1. Thin-Walled Thickness Cup Geometry

Fig. 4 shows the different stages of the cup production. The blank before any forming can be seen in Fig. 4 (a), the two holes in the cup was drilled to help in holding the blank with the mandrel because the support usually used by the tail stock cannot be used here due to that the dynamometer is in-between the tail stock and the mandrel. After the conventional spinning process, the blank was transferred to the cup shape with the walls thickness is the same as the bottom and this is shown in fig. 4 (b) and a section in the conventional spinning cup is shown in fig. 4 (d). The second stage of forming is the transformation of the wall cup to be thinner than the bottom and this is shown in fig. 4 (c) with a sectioned cup in fig. 4 (e), this stage was performed with the balls.

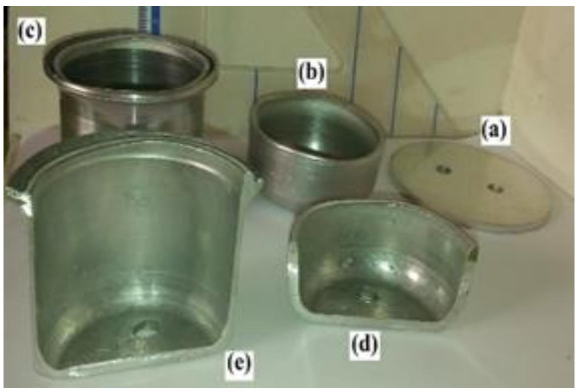


Fig. 4 *Different stages of the cup production.*

The produced cups at different f, Δt, and N are shown in fig. 5 and fig. 6 with the feed and speeds shown on the figure at Δt equals 3mm at all cases. All the produced cups as can be seen from the figures are in good condition except that the cups have a formation of metal piled-up. The shear spinning process at feed of 1.21 mm/rev with different speeds and Δt 3mm was not successful as shown in fig. 7. The failure in the cups at high feed rate of 1.21 mm/rev may be due to the increase in the feed rate increased the force reaction from the metal on the forming balls and this increased the stresses in the metal over the limit of the cup metal.

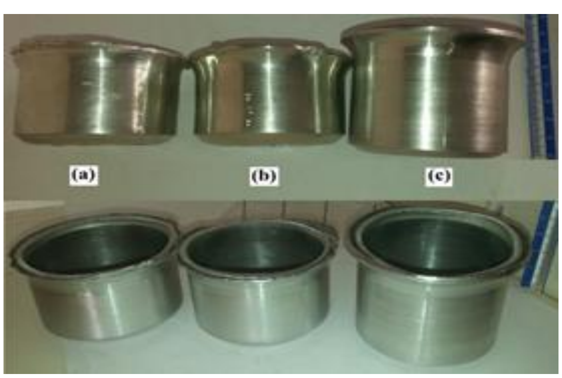
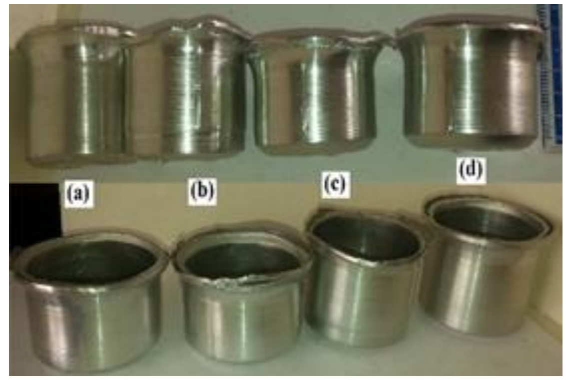


Fig. 5 *photograph for products at different speed, cross in-feed, and axial feed.*



(a) Blank (b) Cup after 1st stage

(c) Cup after 2nd stage (d) Cup section after 1st stage

(e) Cup section after 2nd stage

Fig. 6 *photograph for products at different speed, cross in-feed, and axial feed.*

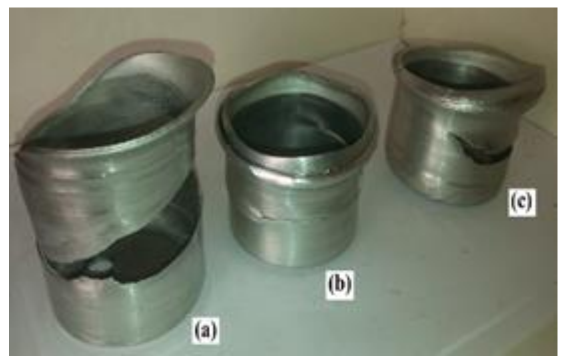


Fig. 7 *photograph for unsuccessful products.*

The second stage of the forming process was performed with the balls are not at the same level, but the balls have in-between distances which can be changed to test its effect on the forming process. The in-between distances are described in table 2 as L1, L2, and L3. Some of the cups produced in second stage are shown in fig. 8. As can be seen from the figure all the cups are in good condition and one of the cups was formed without pile-up forming which is S10 mentioned in table 2. The distances between balls at S10 were 1.66 mm between each ball and the next ball.

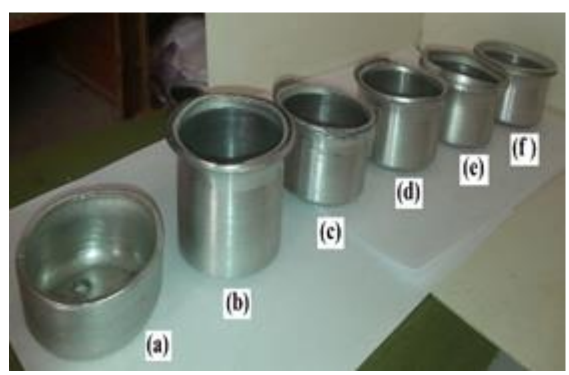


Fig. 8 *photograph for products after second stage, flow forming with Ballizing technique.*

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A comparison between the cup formed with the balls at the same level and with the balls at different levels is shown in fig. 9. A section at the cups with the balls in the same level and in different levels is also shown in fig. 9. The aim of putting the balls at different level was to overcome the pile-up forming occurred at the cups produced before. As can be seen from the result, the pile-up forming was not found at S10 which is obvious at fig. 10.

Fig. 9 *photograph for products with balls at same level and at different levels.*

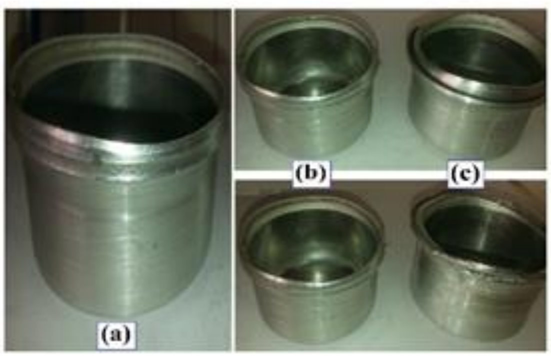

Fig. 10 *photograph for products with and without pile-up.*

3.2. Effects of Mandrel Rotational Speed, N and axial feed, f on forming loads.

Figure (11) illustrates the relationship between the mandrel rotational speed and the forming loads in three different directions (axial, radial and tangential direction) with different axial feeds of (0.3, 0.6, and 0.91 mm/rev) at cross in-feed of (3mm). It can be concluded from the curves that increasing the rotational speed of mandrel decreasing the forming loads in three directions to reach minimum values at mandrel rotational speed about 150 rpm. Hence, with increasing the mandrel rotational speed above 225 rpm the forming loads increases to reach the higher values at the maximum choosing value of mandrel rotational speed. It can be believed that the rate of metal flow decreasing while increasing the rotational speed causing a decrease in the forming load to the optimum shown value. After that, any increase in the rotational speed causing increase in the surface hardness of the specimen, which increases the load as shown. It also shown at Figure (11) that, the forming loads in three directions increased with increasing the feed rate at all cross in-feed, the max value of the force component is the radial force this is due to the nature of the process in which, the first importance is to reduce wall thickness of the cup.

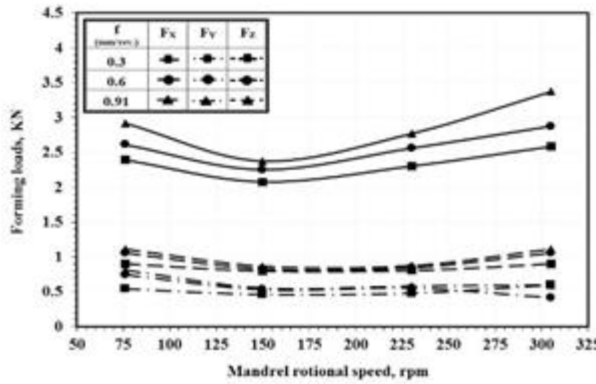

Fig. 11 *Relationship between mandrel rotational speed and the forming loads (balls in same plan).*

Also, the effect of axial feed on forming load is shown in Figure (11). The forming load was increasing with the increasing of axial feed. This is due to increasing the contact area with the increase of axial feed, hence, the pile-up was increased also this raises the forming load components. A comparison between all eighteen samples described in table 2 is shown in fig. 12. The comparison is between the cup total forming force for all samples. The total forming force can be calculated as:

$$F_t = \sqrt[2]{F_x^2 + F_y^2 + F_z^2}$$

As can be concluded from fig. 12, S10 is the best sample due to less force and no pile-up formed in this sample. The exact values of the forming force for S10 and some other samples close for S10 are shown in table 3 for more explanation.

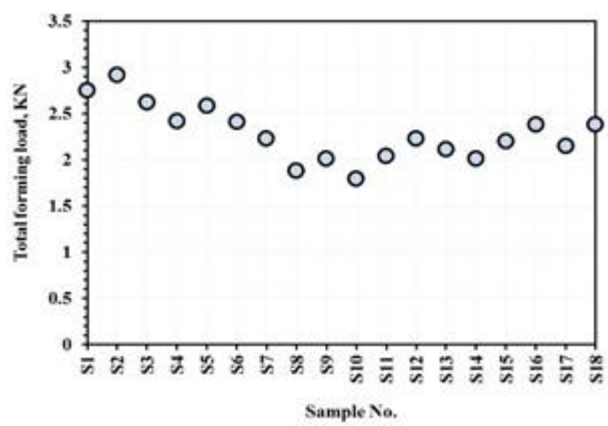

Fig. 12 *the total forming load for samples at different distances between balls centers.*

Table 3 *The values of forming load for defferent case study.*

Case study		The value of forming load
All balls are lie in same plan at N=150 rpm, f=0.3 mm/rev.		2.96 KN
Each ball is lie in deferent plan relative to other balls	(S7) L1+L2+L3=2 mm	2.23 KN
	(S8) L1+L2+L3=1.75 mm	1.93 KN
	(S9) L1+L2+L3=1.5 mm	2.05 KN
	(S10) L1+L2+L3=1.66 mm	1.76 KN
	(S11) L1+L2+L3=1 mm	2.15 KN

4. CONCLUSIONS

From the experimental work the following conclusions can be obtained:

(1) The process is a new simple and low-tooling cost technique, it is true that the process is energy, material and money saving when compared to conventional techniques.
(2) The new design has shown the potential to significantly simultaneously overcome the pile up formation in front of the forming balls.
(3) The forming load increased with increasing of axial feed. Furthermore, the radial load is higher than the tangential and axial loads. Also, it was found that, the axial load component recorded the minimum values.
(4) The best rotational mandrel speed and axial feed respectively were found to be 150 rpm and 0.3 mm/rev. in the range of selected parameters.
(5) The best distance between the balls plans was found to be 1.66 mm when the cross in-feed is divided into forming balls.

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