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Simulation of Semi-Active the Blank Holder Force Control to Prevent Wrinkling and Cracking in Deep Drawing Process

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Abstract. This paper presents simulation of drawing force and thickness deformation in deep drawing which employs semi-active blank holder force control system, to solve the problem of cracking and wrinkling. The method of slab with feed back control failure criteria, was employed to make the modeling system and the semi-active blank holder to prevent wrinkling and cracking in forming low carbon steel sheet, without lubrication (μ=0.4). In this study, the mechanical properties of the material were chosen since that they equivalent to those of low carbon steel with its thickness of 0.2 mm, K = 572 N/mm^2, UTS = 391 N/mm^2, yield stress = 309 N/mm^2 and n = 0.2. The diameter and the depth of the cylindrical cup-shaped product were 40 mm and 10 mm, respectively. Results from simulation have shown that the semi-active blank holder system can control very responsive against changing of deformation condition. The optimum of initial blank holder force is approximately 3000 N up to 4000 N. In the early stages (initial stroke), blank holder force system could be responsive to prevent cracking, and at the end of the punch stroke, it is very effective to prevent wrinkling. Simulation of semi-active blank holder force control system is excellent in model formation to prevent cracking and wrinkling.

Introduction

The blank holder force is one of the veriabel process in deep drawing process, which is very important to be checked further, in order to prevent cracking and wrinkling. Previous research has discussed the determination of blank holder force constantly linear [1] and aims to prevent one of a defect cracks or wrinkles only.

Research conducted by Yagami and Manabe [2], investigated the effect of the blank holder force application against the condition of gap. A larger gap could increase a material flow in tangential direction, and a magnitude of tangential stresses, consequently this condition would affect a wrinkling in the flange. M Gavas and M. Izciler [3][4][7] suggested that the optimum gap is no more than 180% of the material initial thickness, to prevent wrinkling. While Lin Zhong-qin [5], provides information that the value of flange wrinkling height (FWH) and side wall wrinkling height (SWH), should not exceed more than 115% of the initial material thickness. Furthermore, Rode Ibrahim Demirci, Cemal Esner, Mustafa Yasar [5][6], investigated cracking criteria in deep drawing. According to their research informed, the cracking would appear, when the deep drawing force did not exceed the maximum strength of material or no higher than tensile strength of material [5][6][8][9][10][11], and the radial material flow was not very obstructed.

With variable assignment processes data information on the research above, the method to set blank holder force system still using open loop blank holder control system. And it is only used to prevent one of the defective product. Blank holder force is not being set by close loop control system by considering all the factors that lead to wrinkling and cracking.

Based on the literature above, the purpose of this paper is to demonstrate a modelling and a simulation systems by setting the blank holder force control semi-active to prevent both wrinkling and cracking. Furthermore these systems could responsive to real conditions of formation and finally it could prevent cracking and wrinkling. Validation of the simulation by comparing the results with Lin's and Gavas's experiment, related to the condition of Gap criteria and enhancement of material formability.

Modeling of Stress – Force Forming and Material Thickness Deformation.

Refer to stress of state on material, the formation of radial stress would be obtained, as shown in the figure below.

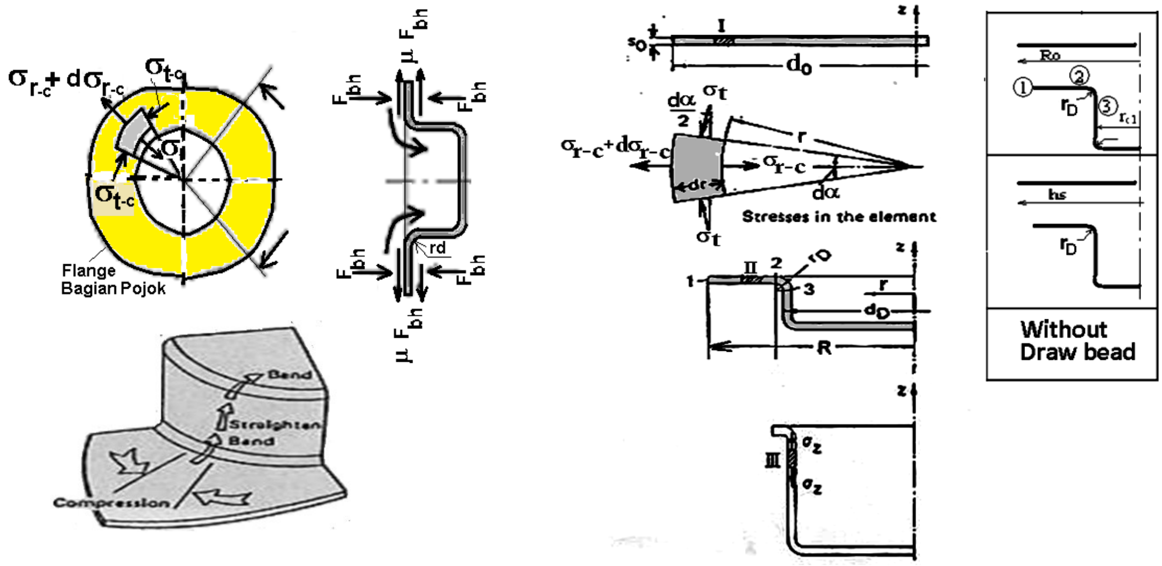


Figure 1. Stress of state and flow stress in deep drawing [10][12][13]

Radial stresses of deformation in the radial direction can be estimated with equation [13]:

$$\sigma_{r\text{-}c} = e^{\mu\alpha}\left\{1.15\sigma_I \ln\left(\frac{d_1}{d_m}\right)+\left(\frac{2\,\mu F_{BhC}}{\pi d_1 s_o}\right)\right\}+\frac{\sigma_{II} s_o}{2r_D} \quad (1)$$

where: μ is friction coefficient; σ_I is mean flow stress on flange (point 1-2); $\sigma_I = [K/(\varepsilon_2-\varepsilon_1)][\varepsilon_2^{n+1}- \varepsilon_1^{n+1}/(n+1)] = (\sigma r\text{-}\sigma t)$; σ_{II} is mean flow stress of material, after bending deformation on die radius; $\sigma_{II} = [0{,}5\ K][\varepsilon_2^{n}+ \varepsilon_3^{n}]$; s_0 is initial material thickness; $F_{bhcorner}$ is blank holder force; d_l is the diameter of a flange; r_D is die radius; $d_m=d_l+s_0$= mean diamater of cup; α is bending angle; F_{BhC} is blank holder force; K is the constant strength of material; n is strain rate exponential; ε is strain of material deformation.

The incremental ε_2, ε_2 and ε_2 can be determined from the change in the forming of material, each stroke and using the assumption of constant volume. Furthermore, the deep drawing force (Fd) to produce cup can be estimated by using the following equation:

$$F_d = = \pi . d_m . s_o \{\sigma_{r\text{-}c}\} \quad (2)$$

The product would crack, if the magnitude of the deep drawing force (Fd) exceed the drawing force criteria of cracking. Therefore the limiting product failure (cracking) or the cracking load can be estimated by using the following equation:

$$F_{crack} \geq F_d \text{ or } \pi . d_m . s_o . UTS \geq F_d \quad (3)$$

Where F_{crack} is the limiting cracking force of material; F_d is the deep drawing force; UTS is the ultimate tensile strenght of material.

Failure criterion of wrinkling can be approached by comparing deformation of material thickness with the initial sheet metal, through the equation:

$$s_1 = s_{final} \geq c . s_o \quad (4)$$

where: c is multiplying factor, that it's depend on material characteristic.

While the mathematical formulations is to determine the final thickness of material is approached from the derivative formula of equation [12]:

$$s_1 = s_o \text{ Exp } \{ [(-\sigma_r - \sigma_t)/(-\sigma_r + 2\sigma_{t.})].\varepsilon_2 \} \quad (5)$$

While the Blank Holder Force (Fbh) follows the equation: [13]

$$Fbh = 10^{-3} \times 2.5 \left[(LDR_{material} - 1)^3 + (0.005\ Do/So) \right] UTS \times contact\ area \quad (6)$$

where: $LDR_{material}$ is Limiting draw ratio of material; Do is Diamater of Blank Sheet; s_o is initial thickness; UTS is Ultimate Tensile Strenght of material.

Setting of The Semi-active Blank Holder Force Simulation System

Set up of the simulation include i.e product dimensions, punch die and process conditions, shown in Figure 2 below.

Meterial of blank sheet: low carbon steel sheet; K= 572 N/mm2 (the constant strength of material); n = 0.2 (strain hardening coefficient); σ_o (yield stress) = 309 N/m^2; Ultimate Tensile Stenght (UTS) = 391 N/mm2; D_o = 67.99 mm; d_p= 50 mm; s_o = 0.2 mm; r_D = *die radius* = 1 mm; punch radius (rp) = 1 mm; deep of product (h) = 10 mm; coefficient of friction (μ)= 0.4 (without lubrication).

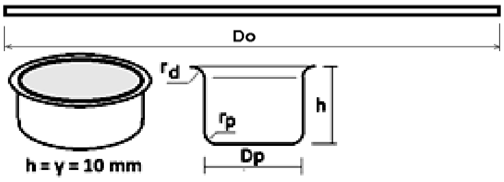
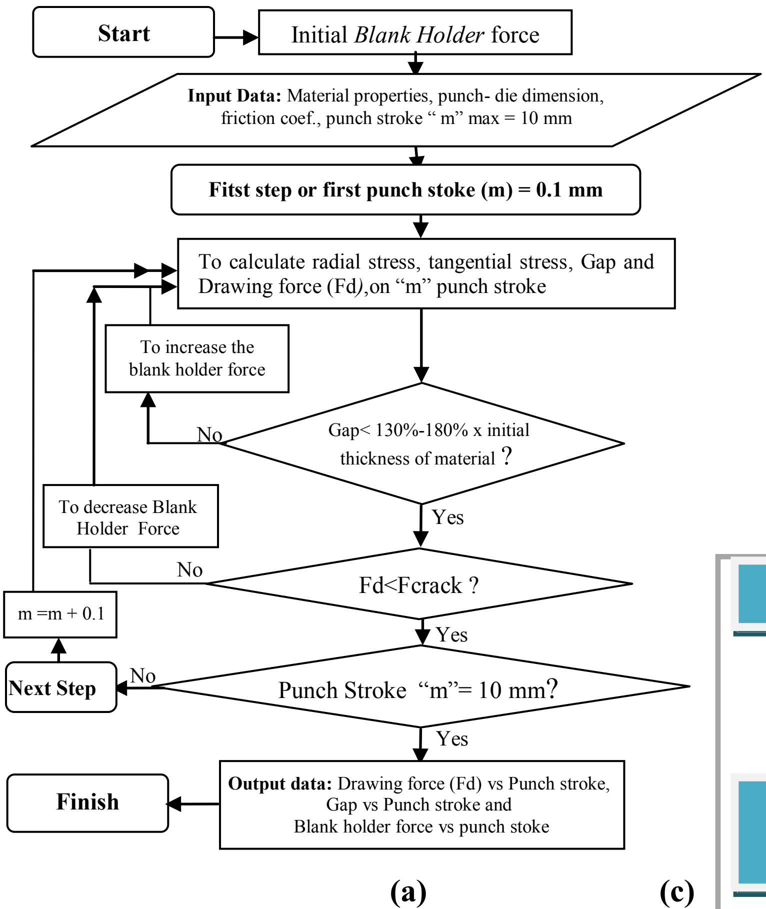
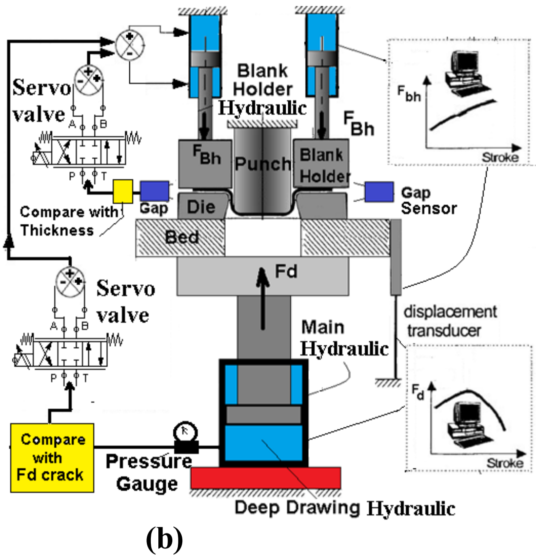


Figure 2. Process conditions, product and punch-die dimensions.

The algorithm system to calculate and to control : stress forming, deep drawing force (Fd), and thickness deformation, can be described as figure 3.





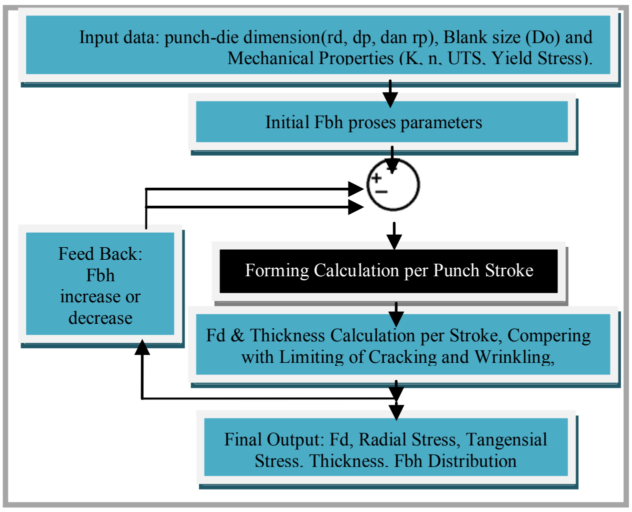
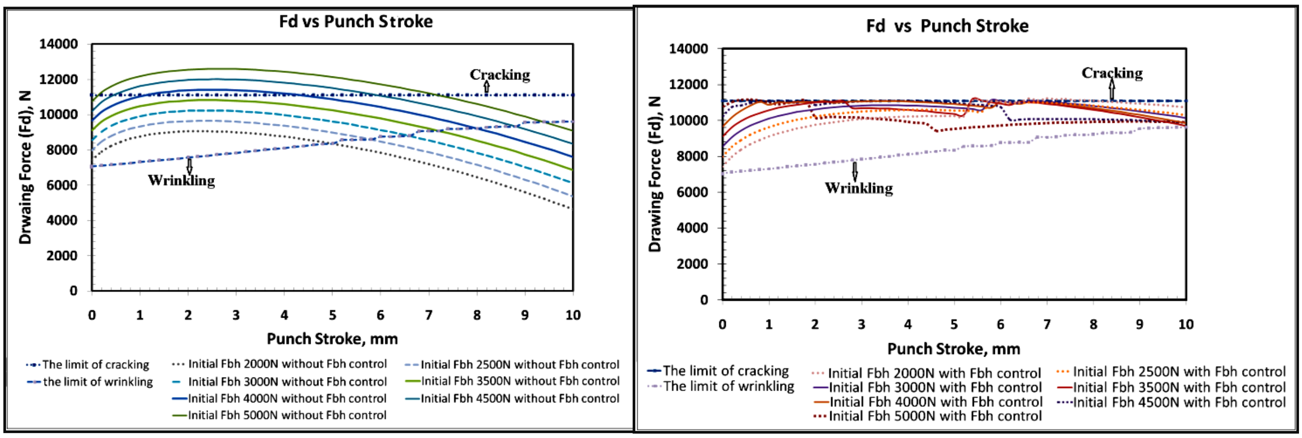


Figure 3. (a). The Algorithm of blank holder force control systems, (b). The semi-active of blank holder force control systems, (c). Modeling system of the blank holder force control system

Before the system is executed, then whole process of design and variable data imputed in simulation program. After all the data is read including the initial blank holder force, furthermore to run the simulation system, by setting the initial blank holder force: begins 2000 N, 2500 N 3500, 3000 N, 4500 N, 4000 N and 5000 N. The results of the simulation recorded covering data: the value of the radial stress, tangential stress, drawing force (Fd) and blank holder force, every step punch stroke. The value of the product failure criteria used to make the system closes loop is gap and drawing force maximum (for wrinkling criteria and cracking criteria). The value of gap and drawing force are compared with failure criteria. Then the result of the comparison give the signal to the blank holder hydraulic and to change magnitude of the blank holder force in real-time condition (adaptive). So the blank holder force is always responsive and able to prevent wrinkling and cracking. If the final thickness of material is greater than 130% initial thickness, then ordered the system spontaneously raised the magnitude of blank holder force. Then, if the magnitude of deep drawing force is higher than the critical limit of cracking force, then the system will reduce the magnitude of blank holder force, and so the system is always recurring until the end of the forming process. The close loop control system persisted up to punch stoke until it reaches a depth of punch 10 mm. So all phases of the system is expected to prevent wrinkling and cracking adaptively.

Results and discussion

The first simulation result is a drawing force distribution with and without blank holder force control applications, as its is shown in Figure 4 a. For the whole application of blank holder 2000 N, 2500 N, 3000 N, 3500 N, 4000 N, 4500 N and 5000 N, would be indicated occurring cracking and wrinkling. If the application blank holder force too high, it would be predicted that the cracking occur at the early of punch stroke, and would be predicted of wrinkling at the end of the punch stroke. Whereas if it is applied to blank holder force is not constant, with the slope of 0.25 would increased the magnitude of blank holder force (starting from 2000 up to 5000 N), then It still not able to prevent cracking in stoke punch position 3 mm. Because in this position, the flow of material would be hampered and the radial tension increase very dramatically. Therefore the adaptive blank holder force control system on each punch stroke, related the conditions of process (drawing force and gap) is required.

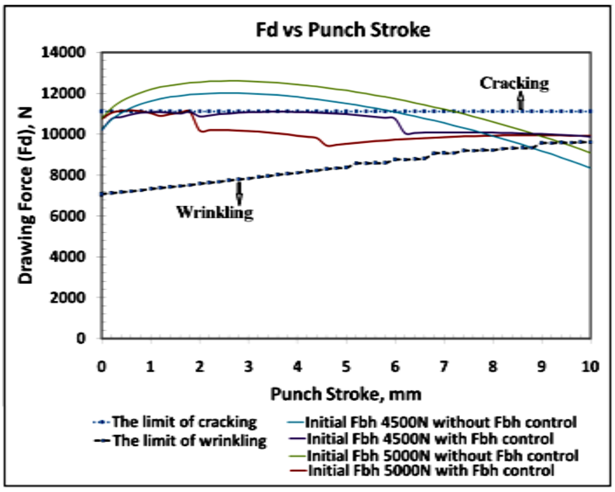


(a) (b)

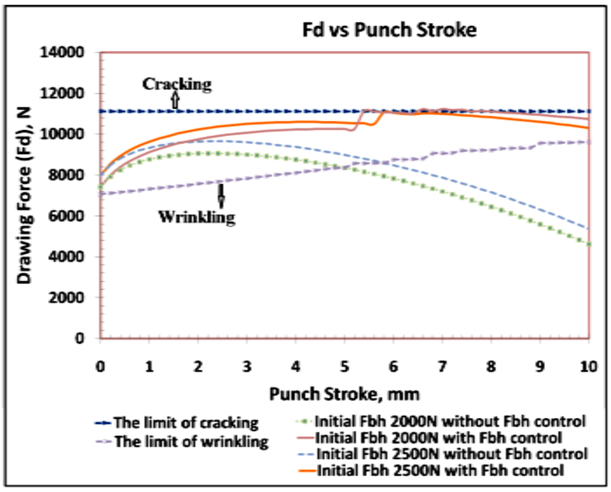
Figure 5. (a). Fd vs Punch Stroke without the semi-active blank holder force control system, (b). Fd vs Punch Stroke with the semi-active blank holder force control system

The critical forming would happen, if the radial stress and the restriction of material flow increase high enough, i.e in a depth of 1 mm - 3 mm (at the early punch stroke). Therefore, the determination of blank holder force must be controlled spontaneously, in order to prevent cracking. Whereas, at the end of stroke punch (in the depth of 6-10 mm), it very potentially occur wrinkles, so the blank holder force should be increased, to prevent wrinkling.

The simulation systems with semi-active blank holder force control showed, that if the initial blank holder force too large (4500 and 5000 N), consequently the blank holder force corrections become very large, which should be reduced for more than 2000 N (the early of punch stroke) spontaneously, to prevent cracking. These phenomenon shown in Figure 6a and 6c.



a.



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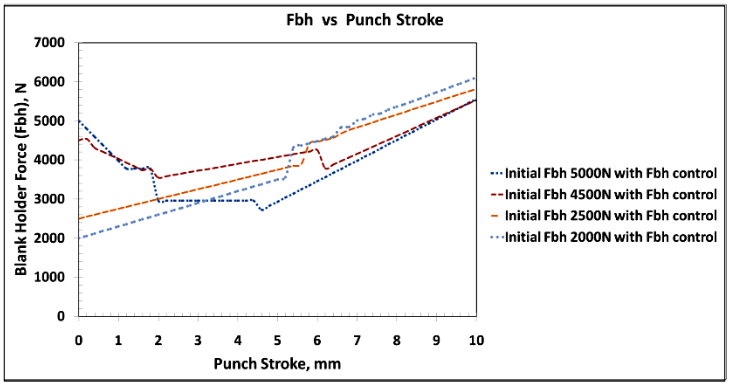
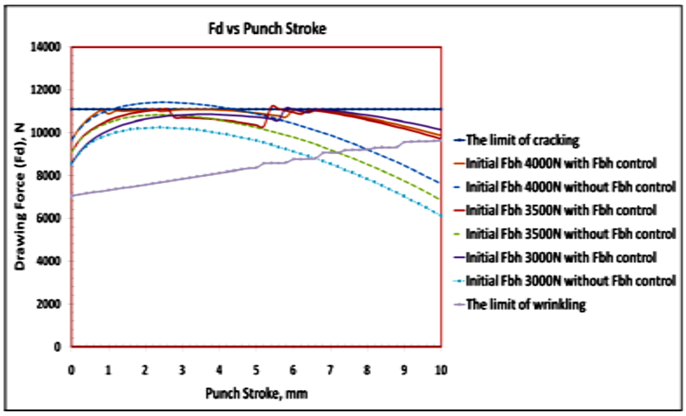


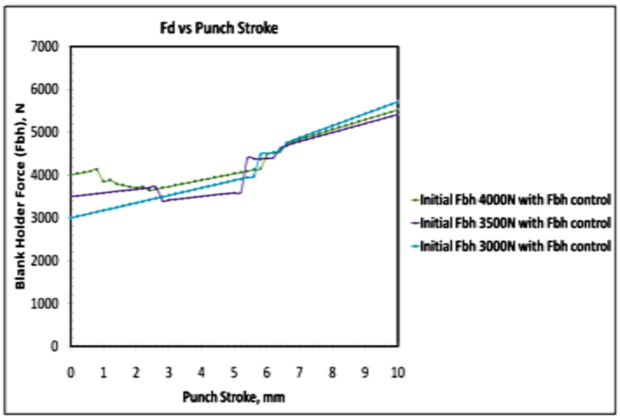
c.

Gambar 6. Fd vs Punch Stroke with and without semi-active blank holder force control system, a. Intial Fbh 4500 N dan 5000 N, b. Initial Fbh 2000 N dan 3000 N, c. Fbh distribusion

By using this system, The initial blank holder force is recommended between 3000 up to 4000 N (as figure 7.a and 7.b). So that the blank holder force would be adaptive to control the flow of materials, the radial and tangential stresses magnitude, the drawing force magnitude and gap effectively.



a



b

Figure 7. a. Fd distrubusion, with and without the semi-active blank holder force control system, b. Fbh distribution will be recommended.

The semi-active blank holder control system would be increases the material formability more than 30 %, so these system can be employed to improve Gavas's and Lin's study (experiment). And the result of simulation agree with Gavas's and Lin's gap criteria, so their method only can be considered feasible to prevent wrinkling.

Conclusion

The semi-active blank holder force control system could respond against the changing of forming process conditions and could prevent the defect of cracking and wrinkling. It indicates that the flow of material and forming stress can be controlled effectively. The optimal condition of initial blank holder force magnitude should be determined in range of 3000 - 4000 N. With the establishment of the initial blank holder force, so that the adaptive blank holder control system will be applied to control the forming process (drawing force and gap) effectively. These conditions will prevent cracking at the early punch stroke, and prevent wrinkling at the end of the punch stroke. The blank holder force magnitude will be changed in a fluctuating around 1000 N. The distribution of blank holder force in every punch stroke on the semi-active blank holder force control could be used as a reference for the process of deep drawing. The semi-active blank holder control system would be increases the material formability more than 30 %, thus it can be employed to improve Lin's and Gavas's study (experiment) [3][7], and can be considered feasible to prevent wrinkling and cracking.

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