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The effect of pre-painting and W-temper forming on springback

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ABSTRACT

The present investigation examined the impact of thermal cycling applied during the painting of sheet steels and the transfer period in the forming of W-temper heat treatment of high-strength aluminum alloy on springback. The U-draw bending test was conducted numerically and experimentally to examine the springback parameters. Pre-painted steel might be aged due to surface cycling during painting and it changes the mechanical characteristics. As a result, pre-painted steel becomes more susceptible to springback. It is also observed that springback is mostly reliant on the amount of transfer time between the W-temper forming of aluminum alloy. To sum up, the interplay among material characteristics, processing techniques, and forming conditions leads to the springback phenomena.

KEYWORDS

high strength aluminum alloy, pre-painted steel, springback, U-draw bending, W-temper heat treatment

1. INTRODUCTION

When materials are deformed and then released, a process known as springback occurs, particularly with metals. It characterizes a material's tendency to totally or partially recover its original shape after deformation [1, 2]. The deformation method and tooling conditions used in the sheet metal, including stamping, bending, and deep drawing might have an impact on springback. It is necessary to identify and compensate for these defects. The most common method to compensate for this impact is to over-bend the stamped pieces. Investigating and understanding their exact causes as well as their relationships to other contributing elements is also necessary. The distribution and magnitude of stresses created during sheet thickness formation are thought to have a major role in the springback phenomenon [1, 3, 4]. A material model that can accurately capture the complex material behavior during unloading is necessary for springback research to be reliable [5, 6]. In addition to the material characteristics of the sheet, springback is often influenced by the Blank Holding Force (BHF) and the contact surfaces' friction coefficient [7]. The BHF is one of the most important factors influencing the contacting surface properties of the tool and sheet [8]. The tool profile radii and sheet thickness have been further impacted. Consequently, a thorough analysis of the various ways in which these parameters affect springback is imperative and demands a high level of expertise with a variety of experimental variables.

Pre-painted materials are still in high demand, and more sectors are starting to use them since pre-painted sheets are more economical, eco-friendly, and produce better-looking surfaces [9]. Additionally, producers can easily get pre-painted sheets from outside vendors, negating the need for an in-plant painting operation [10].

The W-Temper (WT) forming ideal method involves heating high strength aluminum alloy sheet to a specified temperature and rapidly cooling it to increase the sheet's formability. However, the sheet is formed at room temperature and springback continues to be a challenging technological issue. Many studies have looked into the relationship between various

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WT process factors, for example temperature, cooling rate, and holding time. Gronostajski et al. [11] determined the optimal WT condition forming of AA 7075 aluminum alloy for B-pillar through both mathematical modeling and experiment. This study focused on the most important problems that arise during the cold forming of solution-heat-treated sheets and the selection of optimal cooling and temperature settings. Choi et al. [12] studied the mechanical properties of a WT high-strength aluminum alloy using well-modeled constitutive equations and then used the findings for Finite Element (FE) simulations. The U-draw bending test was utilized to assess springback in WT forming. The hardening law and yield function was used to emphasize anisotropic plasticity under loading path modifications in the numerical modeling of springback, which may find use in the cold-forming process. The mechanical behavior of WT sheets formed of 7,075 aluminum alloy was examined by Lee et al. [13] to determine whether the WT forming technology might be used to create accurate vehicle parts or not. Uniaxial and balanced biaxial tension tests, as well as the Nakajima test, were mechanical experiments used to evaluate the basic mechanical characteristics and formability of plastic and elastic materials. Wang et al. [14] comprehensively examine the impact of heat treatment parameters on the stamping deformation and springback of 6,061 aluminum alloy sheets using three-point bending experiments. Furthermore, the mechanism of the sheet springback was examined through the integration of FE numerical modeling. Overall, research on this topic has demonstrated that the WT forming process can successfully reduce springback during metal forming operations; nevertheless, further study is needed to completely understand the relationship between springback and the WT process's characteristics.

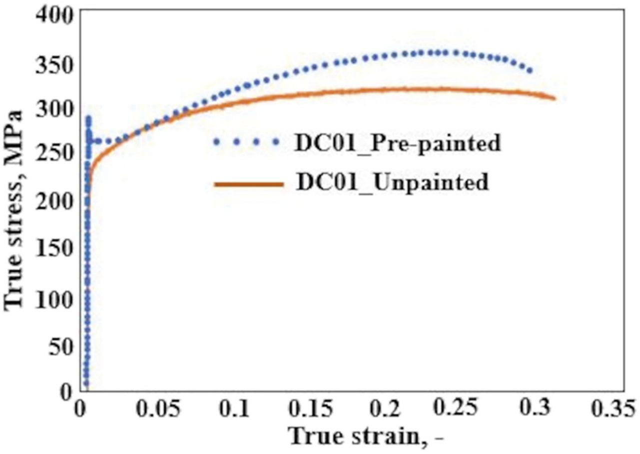

Fig. 1. The true tress-strain diagram of painted and unpainted DC01 steel

This study examined the impact of thermal cycling on springback during the painting of DC01 mild steel before the stamping process, as well as the impact of transfer time during the WT forming process of AA6082 high-strength aluminum alloy. The U-draw bending test was conducted to evaluate the springback amounts. Numerical and experimental investigations have been carried out. The commercial AutoForm-Sigma code [15] was used to do the numerical study.

2. MATERIAL CHARACTERIZATION

2.1. Material characteristics of unpainted and pre-painted steel

A uniaxial tensile test was used to evaluate the mechanical characteristics of the pre-painted and unpainted of DC01 mild steel. The true tress-strain diagram of painted and unpainted sheets is summarized in Fig. 1 and its mechanical and formability behavior is summarized in Table 1. In these cases, the offset yield strength was calculated for unpainted steel due to lacked defined yield strength. In the cause of pre-painted steel, the test resulted in a 9% reduction in upper and lower yield points. However, the pre-painted sheet does not specify the offset yield strength; it simply describes the tensile strength. This type of tensile diagram describes that the steel was aged after rolling. The primary reason for the ageing is that the steel is not deoxidized (inadequate chemical composition, the gases in the steel are not chemically bound). As a result, the sheet material might have experienced artificial ageing via thermal cycling during painting and/or natural ageing if kept at room temperature for a prolonged period. In comparison, the upper yield strength of the pre-painted steel was about 1.5 times higher than that of the unpainted steel at the end of the elastic phase. When the yield strength and tensile strength ratios are compared, almost comparable values are found: 0.6 for the unpainted and 0.8 for the pre-painted.

2.2. WT heat treatment of AA6082

It is noteworthy that the WT heat treatment procedure might be intricate, necessitating exact regulation of both temperature and cooling rate to attain the intended

Table 1. Mechanical and formability behavior of unpainted and pre-painted DC01 steel

Material type	Elastic Modulus, E_0, (GPa)	Lower yield strength, (MPa)	Upper yield strength, (MPa)	Yield strength at 0.2% offset (MPa)	Ultimate tensile strength, (MPa)	Strain hardening exponent n	Total elongation, A_g, (%)
Unpainted	206	–	–	192	322	0.194	24.5
Pre-painted	206	264	290		360	0.133	20.3

outcomes. The performance of the component may be impacted by faults like deformation, cracking, or other effects of improper heat treatment. Therefore, it is crucial to speak with a knowledgeable and experienced heat treatment specialist to receive the greatest possible result. As a result, a specialized furnace is required for the WT heat treatment process. This furnace must be able to accurately control the temperature and maintain a controlled atmosphere or vacuum. As it can be seen in Fig. 2, a forced warm-air heating furnace has been designed and developed for this investigation. Four thermocouples were positioned on the thermal insulation barrel at identical offset distances to control the temperature and provide a uniform temperature distribution. A spatial specimen holder has been designed to hold four specimens at the same time and put them in the thermal insulation barrel.

The temperature profile of the WT forming method utilized in this investigation is displayed in Fig. 3. A Solution Heat Treatment (SHT) was applied to peak-aged as received (T6) aluminum alloy. To achieve a uniform temperature distribution, the sheet material was heated to the desired SHT temperature and held inside the furnace for a while. After that, water was added to the heated material to quickly cool it down to Room Temperature (RT). It should be noted, though, that the holding and Transfer Times (TT) may have an impact on the samples' mechanical characteristics. A U-shaped bending test was conducted, and the impact on springback was examined, at various points in time between the WT heat treatment and the forming operation.

2.3. Tension and unloading tests of WT AA6082

Because they can occasionally be extremely difficult to form while deforming, commercially produced peak-aged T6 tempered AA6082 aluminum alloy sheets fail early in the forming process at room temperature. WT forming is that it improves formability at room temperature and possible in traditional cold stamping. Conversely, springback following cold stamping could pose a serious problem. To accurately predict the springback in the numerical simulation, it is crucial to investigate the Bauschinger effect under cyclic loading and the deterioration of the apparent elastic modulus. To do this, uniaxial tension-unloading tests of WT AA6082 were conducted. The AA6082-T6 aluminum alloy was heated to 525 °C for 30 min to guarantee a homogeneous temperature distribution and that all of the alloying elements had completely dissolved into the aluminum matrix [16]. Water was then used to bring it down to room temperature. Flow stress and apparent elastic modulus degradation were measured during the test at transfer times of approximately 15, 30, 90, and 120 min. It is clear from Figs 4 and 5 that there was a discernible change in the flow

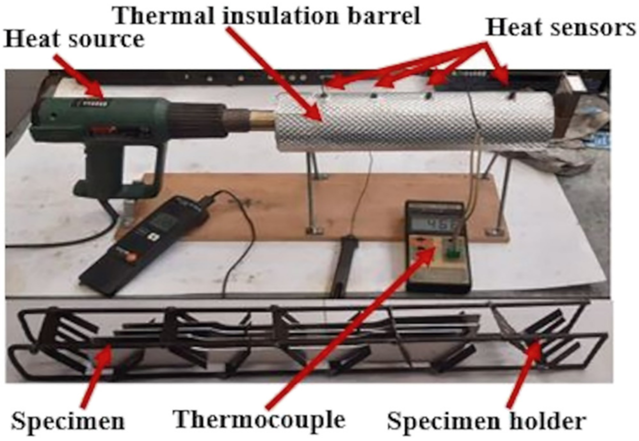

Fig. 2. Forced warm-air heating furnace

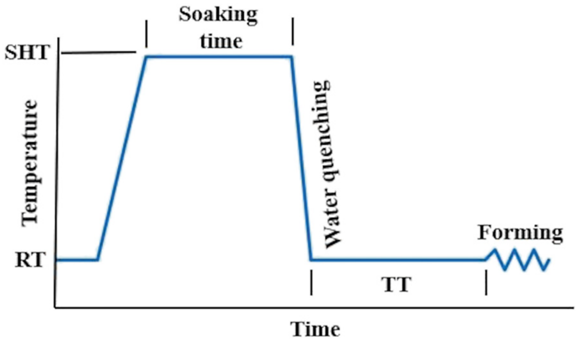

Fig. 3. Temperature profile of the WT forming

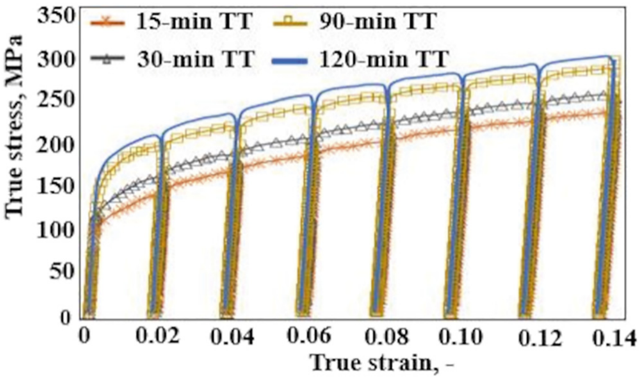

Fig. 4. Tension-unloading test WT AA6082

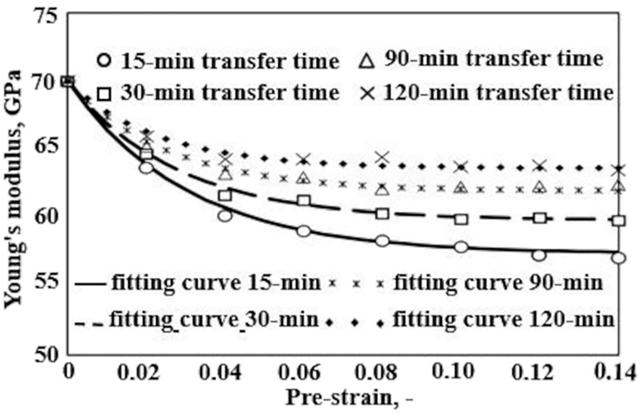

Fig. 5. Reduction of elasticity modulus as a function of pre-strain

stress and a decline in the elastic modulus as a function of deformation at different transfer times.

3. U-DRAW BENDING TEST

U-draw bending test of 250 × 20 × 0.45 mm for unpainted and pre-painted DC01 steel and 250 × 20 × 1 mm for WT AA6082 aluminum alloy was performed numerically using the AutoForm-Sigma commercial code. Due to the numerical simulation of an exceedingly thin sheet, a fine triangular shell element was used. Swift/Hockett Isotropic hardening formula has been used for all materials. Banabic-Balan Criterion (BBC) yield surface has been subjected to unpainted and pre-painted steel. Barlat yield surface criteria were taken into account for aluminum alloy. The model utilized in AutoForm-Sigma for the numerical simulation is shown in Fig. 6.

A novel approach has been devised and implemented in the AutoForm-Sigma commercial code to represent the material's kinematic hardening behavior as equation:

$$E_l = E_0\left(1-\gamma\left(1-\mathrm{e}^{-\chi^{P}}\right)\right) \tag{1}$$

where E_0 is the Young's modulus in (GPa) at zero plastic strain, E_l is the tangent modulus, which ordinarily falls off exponentially as a function of pre-strain P, χ is saturation constant, γ is Young's reduction factor [17].

This study only considers the kinematic hardening parameters that are already pre-defined in the material card of AutoForm-Sigma for unpainted and pre-painted steel materials, as it is shown in Table 2.

The γ and χ values in the numerical simulation of WT formation can be discovered by fitting curves to these observed points with the MATLAB program's curve fitting module [18], as it can be seen in Fig. 5. It can be demonstrated that the average chord modulus value falls with increasing deformation. Consequently, Table 3 displays the kinematic hardening parameters that were ascertained from the fitting curve for the 15, 30, 90, and 120-min transfer time during WT forming. The constant process parameters that were considered for the numerical analysis of all causes are listed in Table 4.

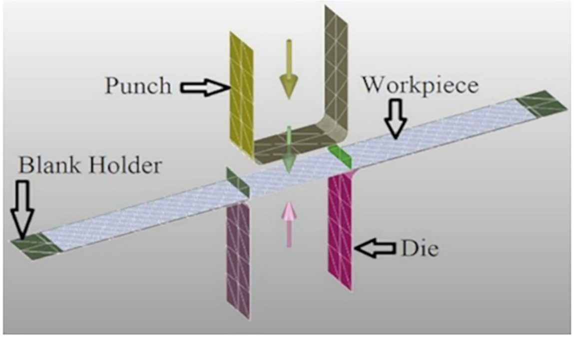

Fig. 6. Models for numerical simulation in AutoForm-Sigma

Table 2. Kinematic hardening behavior for unpainted and pre-painted steel

γ	χ
0.24	40

The U-draw bending test was conducted using the U-bending dies apparatus, which is configured and mounted on a 20 kN hydraulic press machine as depicted in Fig. 7. Both surfaces of the test specimen were uniformly lubricated using grease oil. The die clearance was double the thickness of the sheet on both sides. Table 5 displays the constant variables and their respective levels for the experiment.

4. RESULTS AND DISCUSSION

The amount of springback of each test was measured using NUMISHEET '93 benchmark standard [19] as it is shown in Fig. 8.

Table 3. Kinematic hardening behavior for WT AA6082

Aging time	γ	χ
15-min	0.180	33.3
30-min	0.145	36.6
90-min	0.115	39.2
120-min	0.091	43.1

Table 4. Constant process parameters and their level for the simulation

Parameters	Level
Die and punch radii	5 mm
BHF	3, 5, 7 kN
Coefficient of friction, μ	0.08

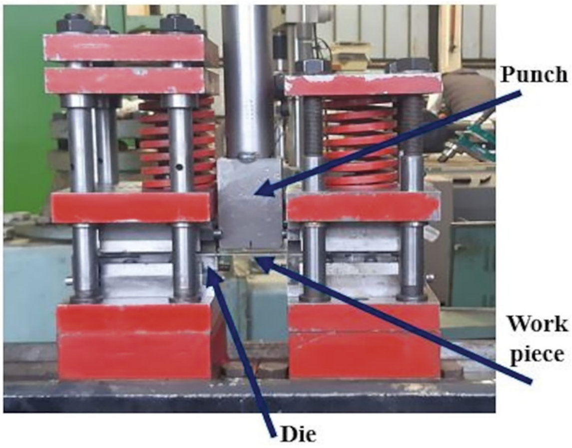

Fig. 7. U-draw bending die apparatus

4.1. Effect of pre-painting before stamping on springback

Figure 9 shows the springback levels for the unpainted and pre-painted steel in both the experimental and numerical simulations as a function of the BHF. The deviation of angles from the origin and the BHF has inverse relationships, according to every computational and experimental test conducted on the two materials. All springback angles decrease with increasing BHF because the strains are distributed more evenly throughout the sheet's thickness. It can be seen that the springback angles obtained from the numerical analysis for unpainted steel are in moderate agreement with the experimental data, especially at higher BHF levels. The springback values for pre-painted steel varied somewhat from those found in the experiment because the impact of paint materials on the coefficient of friction was not taken into consideration in the numerical simulation. Therefore, to take into consideration, the effect of paint material on the coefficient of friction, additional modifications to the numerical simulation are required.

Table 5. Constant process parameters and their level for the experiment

Parameters	Level
Die and punch radii	5 mm
BHF	3, 5, 7 kN
Lubrication condition	Grease oil

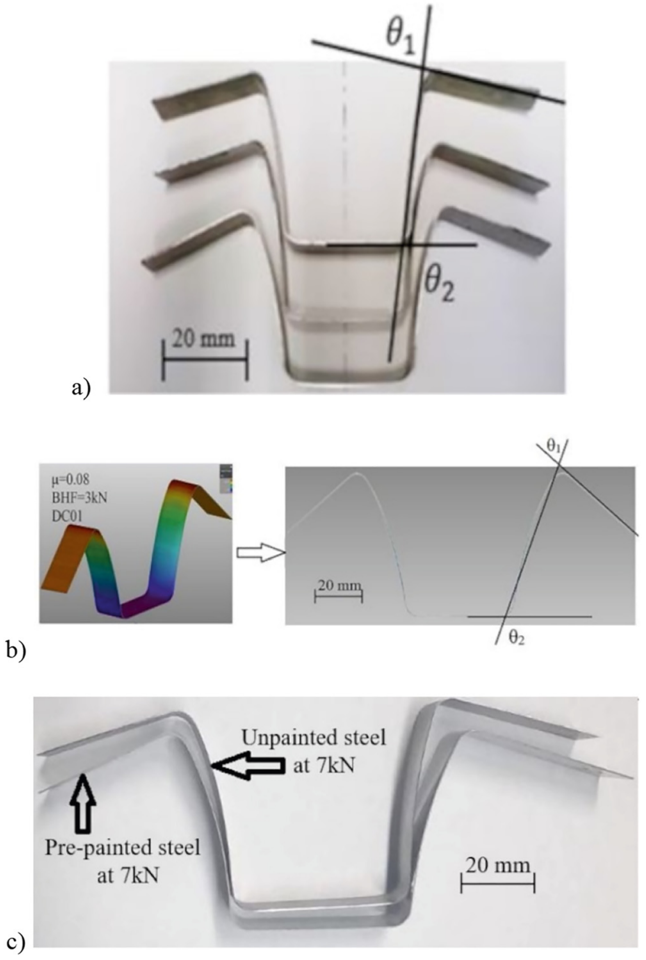

Fig. 8. NUMISHEET '93 benchmark standard for springback prediction [19], a) WT AA6082 at 15-min transfer time, b) unpainted steel at 3 kN BHF, c) the difference of springback for unpainted and pre-painted steel at 7 kN BHF

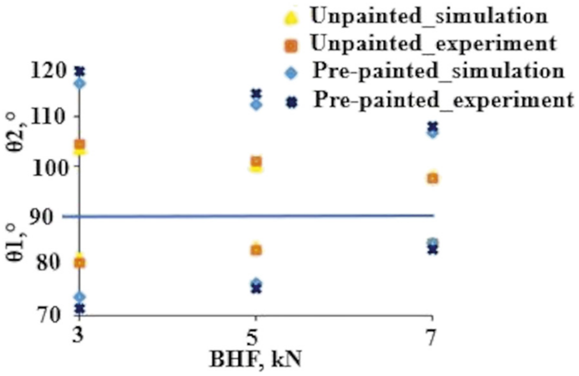

Fig. 9. Effect pre-paint on springback as a function of BHF

4.2. Effect of transfer time in WT forming on springback

The alloy's springback may be affected by how long the AA6082 WT aluminum alloy is transferred to the forming process. An orthographical view of how springback changed as transfer time and BHF increased as it is shown in Fig. 10. A longer transfer interval between the WT heat treatment and the stamping process may result in a higher springback angle because it allows the material more time to assume its ultimate shape as it ages. The transmission time and the angle deviation θ_1 have an inverse relationship. However, Fig. 11 shows that there is a straight link for θ_2. Springback angle was unaffected by extending the transfer period since the material may naturally age to some extent, which could increase strength while decreasing ductility. Because of this, it's crucial to carefully tailor the transfer period for the specific application and material being used, taking other factors like cost and manufacturing efficiency into account.

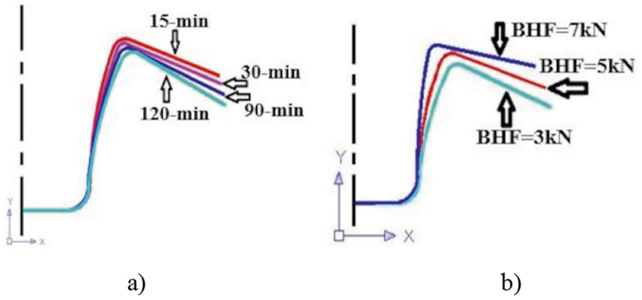

Fig. 10. a) Effect of transfer time at 5 kN, b) effect of BHF at 15-min edging time

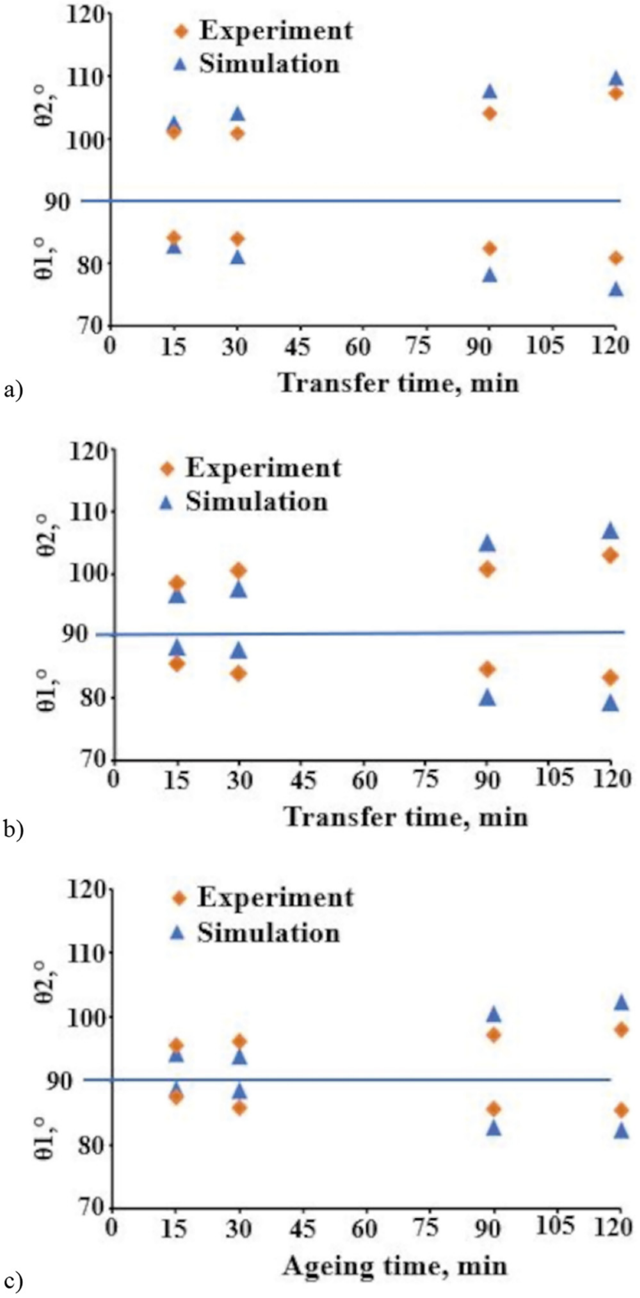

Fig. 11. Effect of transfer time on springback angle a) at 3 kN BHF, b) at 5 kN BHF, c) at 7 kN BHF

Additionally, BHF affects the springback. This is because, throughout the forming process, the blank holding force aids in distributing the deformation throughout the sheet metal in an even manner. The outcome is a more uniform distribution of stresses with less residual stresses, which lessens the material's propensity to revert to its initial form after formation. It is crucial to remember that going above a specific blank holding force threshold may cause other issues like excessive material tearing or thinning. As a result, the ideal blank holding force must be ascertained using the material's particular characteristics and the forming environment.

5. CONCLUSIONS

The optimized treatment applied to the material affected the mechanical characteristics and it implies to impact on the springback. Thermal cycling during the painting of the steel sheets affects the material characteristics, springback behavior, and the entire deformation process. In the U-draw bending test, springback parameters have a greater impact on pre-painted steel sheets than on unpainted sheets. High-strength aluminum alloys can have their mechanical qualities and performance. Those are greatly enhanced by the extremely efficient heat treatment parameters in WT forming. The accurate prediction of the springback phenomenon is achieved by the interplay of material characteristics and treatment procedures in WT formation conditions. Engineers and manufacturers must carefully consider these factors and employ suitable techniques to minimize or regulate springback to obtain the desired forms and dimensions in the product.

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