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Opportunities, Challenges, and Influencing Factors in the Forming of Preconditioned Semi-Finished Products Made of EN AW-6082 and -7075

Janosch Günzel, Joachim Hauß, and Peter Groche*

The aluminum alloys EN AW-6082 and -7075 possess a high specific strength and are therefore predestined lightweight materials. In the high-strength T6 state, however, they exhibit low cold formability and a pronounced springback. For this reason, temperature-supported process routes such as warm or hot forming are currently used to form these alloys. Cold forming of preconditioned semi-finished products in the W-Temper (W) or soft-annealed (O) condition offers an alternative. The upstream heat treatments lead to a significant expansion of formability, making conventional cold forming possible. This comes along with more robust process conditions. After the forming operations, a heat treatment is required to obtain the high-strength T6 properties. Herein, the opportunities, but also the challenges, of preconditioning are highlighted on the basis of material characterization and single-stage as well as multistage forming experiments. Special attention is paid to the relevant process variables and their influences regarding process robustness. This also includes subsequent heat treatment to exploit the lightweight potential.

1. Introduction

Increasing energy prices, growing environmental awareness among the population,[1] as well as legal requirements such as the European Union's target of reducing energy consumption by at least 32.5% by 2030[2] are making energy efficiency an increasingly important issue. Especially in the automotive sector, lightweight construction is becoming progressively important due to strict regulations on CO_2 emissions with limits for new registrations of 95 g CO_2 km^{-1}.[3] For this reason, aluminum is an important lightweight construction material, which is also reflected in the continuous rise of the average aluminum content per car, which was 179.2 kg in 2019 and is expected to increase to 198.8 kg in 2025.[4]

While this increase is currently determined mainly by cast components, an increase in sheet metal and extrusion parts is expected in the future.[4] The most common alloys used for the automotive structural parts and body-in-white are the medium-strength alloys of the 5××× and 6××× series.[5] The electrification of drives will ensure a further increase of the lightweight material aluminum.[4] The greatest potential is offered by the high-strength alloys of the 7××× series. With a tensile strength of at least 540 N mm^{-2} in the T6 state,[6] for example, the alloy EN AW-7075 offers a high potential for various lightweight applications, as shown in **Figure 1**a.

The applicability of aluminum alloys in the high-strength T6 (solution heat-treated, quenched, and artificially aged to maximum strength[7]) state is limited by poor cold formability and high springback. This can be seen in Figure 1b. While a specimen of EN AW-6082 is formable in the cup draw example, the part made of EN AW-7075 breaks into several pieces.[8] Even if forming is possible, the springback behavior of the higher strength alloy poses a further challenge, as shown by the 90° die bending with a 20 mm radius in Figure 1b.[9]

To extend formability[10,11] and reduce springback,[11,12] higher temperatures and thus temperature-supported process routes are applied. The possible process routes for forming medium- and high-strength aluminum alloys are shown in **Figure 2**. In warm forming, the sheet is heated in a furnace to an alloy-dependent temperature of 150–300 °C[13] or directly heated in a contact heating station to 200 °C within seconds[14] before being immediately formed in an isothermal tool. The main advantage here is the retention of the original material properties due to the short temperature load, so that no subsequent heat treatment is required in case of an initial T6 state.[13] In hot forming, the sheet is solution heat treated at an alloy-dependent temperature of 470–530 °C prior to forming and simultaneously quenched in the cold tool. Subsequently, artificial aging is required to achieve high-strength T6 properties, which is often achieved during the e-coat process in an industrial environment.[14]

J. Günzel, P. Groche
Institute for Production Engineering and Forming Machines
Technical University of Darmstadt
Otto-Berndt-Straße 2, 64287 Darmstadt, Germany
E-mail: guenzel@ptu.tu-darmstadt.de

J. Günzel, J. Hauß
Development
Werner Schmid GmbH
Weichselstraße 21, 36043 Fulda, Germany

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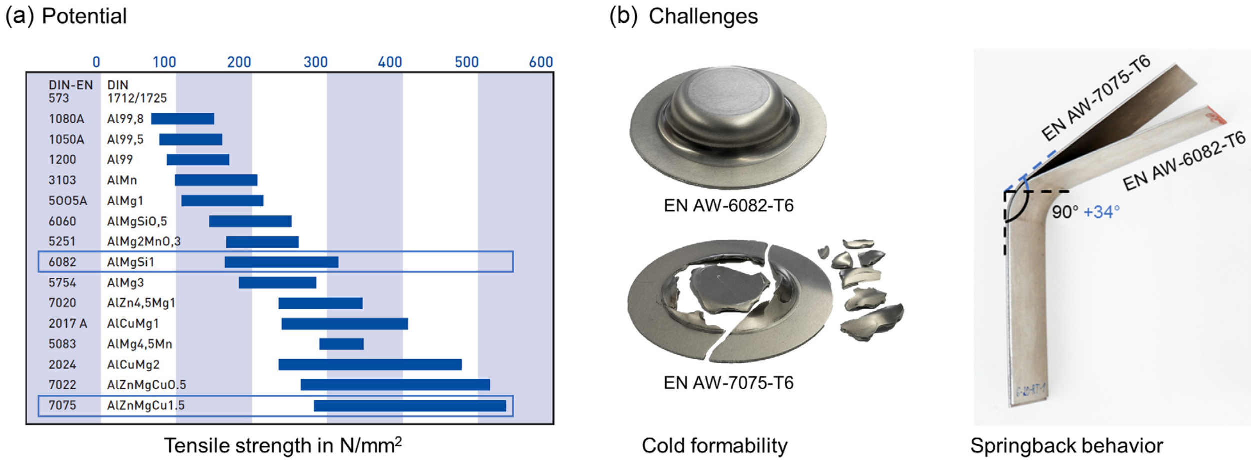

Figure 1. a) Strength ranges of wrought aluminum alloys (Reproduced with permission.[20] 2007, GDA) and b) challenges in cold forming in the high-strength T6 condition.

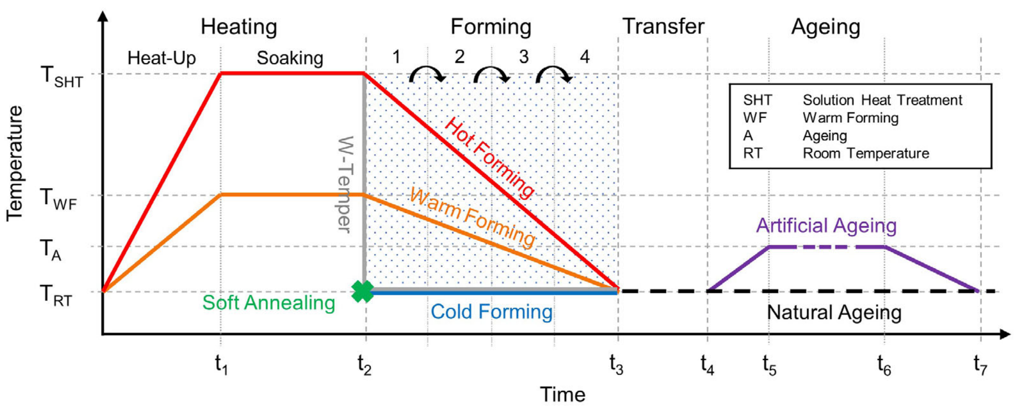

Figure 2. Process routes for forming high-strength aluminum alloys (based on ref. [31]).

Although both warm and hot forming lead to expanded formability, they also present some challenges due to the high temperatures involved.[10] The temperature control of the processes requires additional peripherals for heating or cooling of sheets,[10] complex temperature-controlled forming tools, and fast handling systems to address the temperature sensitivity of the material, thus causing higher costs and cycle times.[5] Further aspects are the increased adhesive tool wear[15] and inferior surface finish,[10] which occur at elevated temperatures with inadequate lubrication.[15] Compared to cold forming, completely different lubricants and application methods are used here.[16]

Alternatively, there is the possibility of cold forming preconditioned semi-finished products in the unstable W-Temper (solution heat-treated and quenched[7])[10] or stable O (annealed[7])[17] state. The upstream heat treatment leads to lower strengths and enlarged elongations compared to the T6 state and thus enables forming at room temperature.[18] The relevant process parameters for producing the two conditions are explained in more detail in the following chapter.

The main advantages of cold forming medium- and high-strength aluminum alloys include the use of conventional dies[14] and lubricants as well as the less affected component surface quality and the lower forming cycle times.[10] This is contrasted on the one side by the need for subsequent heat treatment to achieve the high-strength T6 material properties[14] and on the other side by pronounced strain hardening.[8]

In multistage forming, as required to produce complex components, the above process routes are challenging because of the heat transfer[18] that occurs in warm and hot forming and strain hardening[8] in cold forming.

In terms of process robustness, multistage forming with its error propagation across the single stages exhibits a high susceptibility to process fluctuations. Thermomechanical processes inevitably lead to many other influencing factors, since a large number of parameters are temperature-dependent, influence each other, and thus make it more difficult to achieve steady states. The influence of individual parameters (e.g., material properties, blank holder force, or coefficient of friction) on geometric component characteristics is already evident in single-stage cold forming.[19]

Various studies already exist on individual aspects of preconditioned semi-finished products, but this paper's holistic view and comparison of three heat-treatment states and two alloys allows for more in-depth comparisons across the entire process chain. In addition, the multistage process is a very special field of application, which complexity requires further investigations.

2. Preconditioned Semi-Finished Products

The medium- and high-strength aluminum alloys EN AW-6082 and -7075 and the process routes for their preconditioning into the W-Temper as well as soft annealed O state are described later.

2.1. Materials

EN AW-6082 and -7075 belong to the heat-treatable aluminum alloy classes and are used in the investigations described in this paper in the high-strength T6 state with a thickness of 1.5 mm. Characteristic of the 6××× alloy is the magnesium and silicon content, while zinc and copper being the main alloying elements in 7075. The exact chemical composition of the alloys can be found in **Table 1**.

2.2. W-Temper

The production of the W-Temper condition is always based on solution heat treatment followed by quenching, but the specifications on time and temperature vary, depending on the alloy and the literature source. For EN AW-6082, temperatures of 525–540 °C,[20] 530 ± 10 °C,[21] or 535 °C[22] are used, whereas 470–480 °C,[20] 465 ± 5 °C,[21] or 475–480 °C[23] are used for EN AW-7075. At these temperatures, the samples are solution annealed for 5[5,24] or 10[23] up to 30 min.[25] Meanwhile, the alloying elements are dissolved in the aluminum crystal.[20]

The critical temperature range for subsequent quenching is specified to 400–290 °C,[21] respectively, 400–200 °C,[20] and the critical quenching rates are 11,3 K s^{-1} for EN AW-6082 and 100 K s^{-1} for EN AW-7075.[21] These quenching rates are mostly achieved by water quenching,[5,10,25,26] sometimes with added glycol,[27,28] but there are also tests with forced air[10,24] or between cooled tool plates to avoid distortion.[14,23,28] If the critical quenching rate is achieved, the formation of precipitates is suppressed and the alloying elements remain uniformly and finely distributed, resulting in a supersaturated state.[20] These properties extend the formability and reduce springback.[10]

Due to the unstable state caused by fast natural aging, a time window of 10 min,[5] respectively, 30 min[24] is recommended for the forming process. Subsequently, the formed components are artificially aged so that they assume a stable state and take on the initial T6 properties.[14]

In the current contribution, the heat treatment to produce the W-Temper condition is implemented as follows (cf. **Figure 3**a):

Table 1. Chemical composition of EN AW-6082 and -7075.[32,33]

Chemical elements [wt%]	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others
EN AW-6082 – T6	0.98	0.46	0.06	0.55	0.94	0.03	0.06	0.02	0.01
EN AW-7075 – T6	0.08	0.12	1.60	0.04	2.70	0.19	5.90	0.05	0.14

The sheets are placed in the forced convection chamber furnace preheated to 530 °C (EN AW-6082) or 480 °C (EN AW-7075) and remain there for a total of 8 min. After ≈5 min, the sheets reach the set solution annealing temperature and are held for 3 min. Afterward, the blanks are quickly quenched in a 15% polymer solution out of Serviscol 98-AL from Burgdorf and are formed within a few minutes. The polymer quenchant thereby creates a smaller vapor layer, which ensures more uniform cooling and thus less distortion.

2.3. O (Soft Annealed)

For soft annealing of the material, the sheets are heated to an alloy-dependent temperature of 380–420 °C and are held for 1–2 h (EN AW-6082) or 2–3 h (EN AW-7075).[20] Others use a temperature of 415 ± 10 °C and maintain this for at least 1 h.[7] To achieve a fine-grained structure during soft annealing, a short heating time is favorable.[21] This is followed by a defined furnace cooling at 30 °C h^{-1}[7,20,21] to 230 °C with a holding time of 2 h,[7] respectively, 250 °C for EN AW-6082 or 230 °C including a holding time of 3–5 h for EN AW-7075.[20] This cooling should not be too fast to avoid oversaturation of the α solid solution and thus an unstable state due to secondary hardening effects.[21] Finally, the sheets are cooled down to room temperature in air.[7,21]

This creates a fine-grained and fully recrystallized microstructure, which generally ensures the best forming properties for these alloys.[21] As the strength of the material decreases considerably, a downstream heat treatment is required to maintain the high-strength properties.

Based on the process parameters used in the literature, the heat treatment to produce the soft annealed O condition is implemented as follows during the forming experiments (cf. Figure 3b): The sheets are heated in a forced convection chamber furnace to 410 °C and held at this temperature for 2 h. Subsequently, the sheets are cooled down to 260 °C (EN AW-6082) or 230 °C (EN AW-7075) at a controlled rate of 30 °C h^{-1} and held for a further 2 h before cooling in air.

2.4. Material Properties

To characterize the material properties, tensile tests are conducted for the two materials in each of the three states. For this purpose, flat tensile specimens of shape H (75 mm long, 12.5 mm wide) to DIN 50 125 are used and drawn with 0.2 mm s^{-1} on a Zwick Roell 100 tensile compression testing machine with a nominal force of 100 kN. The stress–strain curves in **Figure 4** show a significant influence of preconditioning. For both alloys, a reduction in strength occurs in the W-Temper, but especially in the O-state, while noticeable differences appear in elongation. In the case of alloy EN AW-6082, the soft-annealed O-state exhibits the highest elongation at break, whereas for EN AW-7075 this is achieved in the W-Temper state.

The three repetitions per constellation result in the mean values for ultimate tensile strength (UTS), yield strength (YS), and the elongation at break (EL), as shown in **Table 2**. Based on the different percentage changes with respect to the T6 initial condition, the ratio of ultimate tensile strength to yield strength

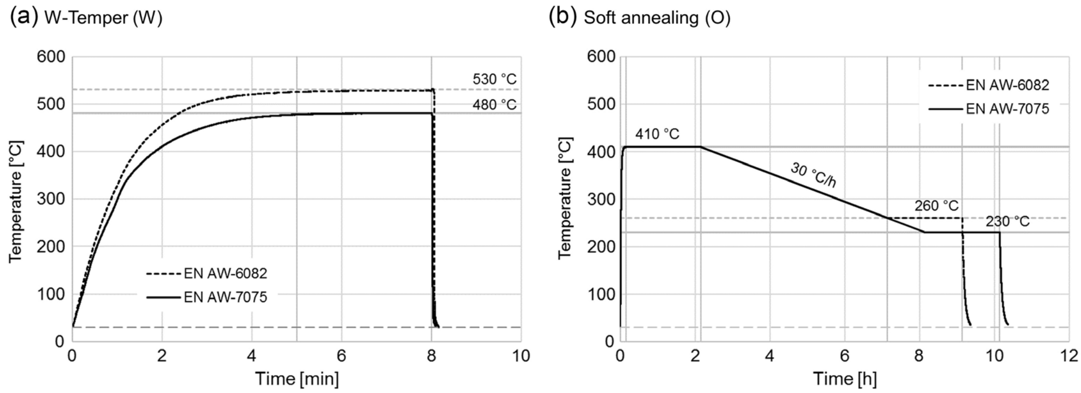

Figure 3. Sequence of the heat-treatment process to adjust the a) W-Temper- and b) O-condition for EN AW-6082 and -7075.

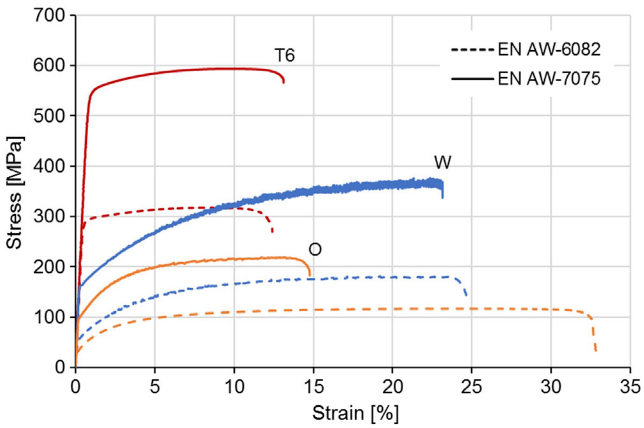

Figure 4. Stress–strain curves for EN AW-6082 and -7075 in the T6-, W-, and O-conditions.

Table 2. Mechanical properties of EN AW-6082 and -7075 in different heat treatment conditions and the percentage deviations from the high-strength T6-state.

Alloy – condition	UTS [MPa]		YS [MPa]		EL [%]	
EN AW-6082 – T6	316.12	–	289.10	–	12.04	–
EN AW-6082 – W	183.65	−41.9%	59.48	−79.4%	24.49	+103.4%
EN AW-6082 – O	115.90	−63.3%	38.79	−86.6%	32.38	+168.9%
EN AW-7075 – T6	587.59	–	531.27	–	11.78	–
EN AW-7075 – W	374.29	−36.3%	164.93	−69.0%	21.76	+84.7%
EN AW-7075 – O	218.40	−62.8%	104.80	−80.3%	15.00	+27.3%

(UTS/YS) increases due to preconditioning. This is equivalent to a significantly more pronounced strain hardening during cold forming. With increasing strain hardening, the forming limit curve (FLC) is shifted to higher principal strain ϕ_1 and thus the forming capacity is extended.[29]

A special phenomenon of the W-Temper condition can be seen in the shape of the stress–strain curve of the alloy EN AW-7075. The stress fluctuations increasing with increasing elongation are known as the Portevin-Le-Chatellier (PLC) effect[21] and occur with rapidly quenched specimens and a short natural aging time.[23] The occurrence of instabilities leading to dynamic strain aging is a thermally activated process that mainly appears in alloys with more than 0.5% Mg (EN AW-7075: 2.7%) and is both temperature and strain rate dependent. In case of cold forming at low forming speeds, the PLC effect increases the strain hardening rate.[21]

The optically visible, strip-shaped roughening of the material surface, which occurs at an angle of 50°–60° to the main stress direction,[21] is only visible on the slowly drawn tensile specimens and does not occur at the formed components, as **Figure 5** illustrates using measurements with the confocal white light microscope µsurf expert from Nanofocus. The formation of flow figures not only prevents the use in visible components, but also initiates the necking process and shear fracture at the same time due to material and geometric inhomogeneities. In addition, the PLC effect can cause negative strain rate sensitivity.[21] To avoid this effect and thus unwanted surface defects, appropriate forming speeds should be used, which should be common in industrial series production.

3. Investigation of the Influencing Parameters

Based on the standard constellations of the T6, W, and O states shown earlier, the individual influencing parameters of the preconditioning (e.g., temperatures and holding times) and the forming characteristics are examined in more detail later.

This publication refers to results on the quenching method[28] with the corresponding quenching rates[18] as well as the influence of the natural aging time with the W-Temper[8] studied in previous publications. In particular, the alloy EN AW-7075 is temperature sensitive and requires high quenching rates, such as can be achieved by quenching in water with 752.1 °C s^{-1} or in the tool with 140.6 °C s^{-1}. Tool quenching requires full-surface, pressurized contact between two cooled tool components. A lower quenching rate, e.g., of silent air with 1.4 °C s^{-1}, is not sufficient to achieve the desired material properties.[18] Due to the instability of the W-Temper state, which provides a rapid increase in hardness and stress and thus influences formability, forming should be performed within a few minutes after quenching.[28] Additionally, the 7××× alloy is more sensitive to natural aging than the 6××× alloy.[8]

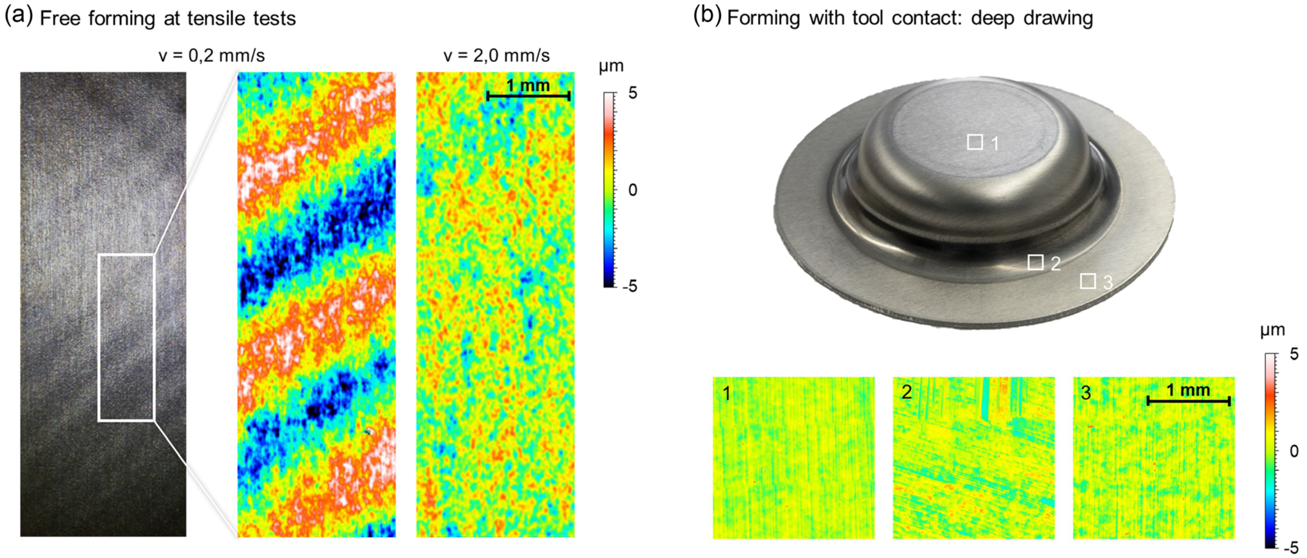

Figure 5. a) Portevin-Le-Chatellier effect during free forming and b) deep drawing of EN AW-7075 in W-Temper condition.

For a more precise characterization of individual influencing parameters, the following process parameters of preconditioning and forming are varied within the tensile tests: 1) The drawing speed v_{draw} is reduced from the standard 0.2 mm s^{-1} by a factor of 10–0.02 mm s^{-1} or increased to 2.0 mm s^{-1} for all three conditions. 2) The rolling direction of the material is examined at 0° as well as 45° and 90° for all conditions to investigate potential anisotropic material behavior. 3) With the W-Temper, the influence of the heating method is also varied, as this also allows the option of inline heating in the tool to be compared. Besides a chamber furnace (F_{old}), a forced convection chamber furnace (F_{new}) and a contact heating unit (CHU) are also used. 4) The alloy-dependent solution heat treatment temperature T_{SHT} from 530 °C (EN AW-6082) and 480 °C (EN AW-7075) is modified by ±10 and ±20 °C. 5) The solution heat treatment time t_{SHT} is changed from 3 min to 1, 8 and 15 min. 6) In the case of soft annealing, the second holding time t_{h} is reduced from 2 to 1 h or dispensed completely to evaluate whether the heat treatment cycle can be shortened.

The influences of the parameter variations on the ultimate tensile strength, the yield strength, and the elongation at break for the initial state T6 in comparison to the preconditioned states W and O for the two materials EN AW-6082 and -7075 are shown in **Figure 6**. The reference constellation is depicted in the middle and all variations contain the change of one parameter at a time.

In general, the significant reduction in tensile strength and yield strength of both materials due to preconditioning is evident, as can already be seen in Figure 4. Both alloys behave in a similar way. The low yield strength in the W- and O-condition leads to earlier plastic deformation of the material. In combination with the higher elongations at break, this results in an improved formability. Regarding the elongation at break, an obvious difference in the material characteristics can be seen: while the soft annealed condition allows the highest elongations of the alloy EN AW-6082, the largest elongations for EN AW-7075 are possible in the W-condition. The 6082 alloy reacts much more sensitive to parameter changes.

A closer look at the individual influencing parameters reveals that all strength values are very reproducible (with three tests per constellation) and that there are no significant differences between the parameter variations. Especially the T6- and *O*-conditions show very constant values, and the parameter variations lead to maximum deviations of the mean value from the initial constellation of less than 4%. Even in the unstable W-Temper state, the fluctuations are below 10%, apart from the variation of the solution heat treatment temperature for EN AW-6082 with maximum fluctuations of 10.9% for the tensile strength and 20.6% for the yield strength. There is a clear trend in solution heat-treatment temperatures: the higher the temperature, the greater the strength. The reason for the significantly larger variations in the W-Temper is the instability of the material and thus its time dependence, which can influence the results despite the greatest care taken in the execution of the tests. The human influences here occur mainly during the handling of the blanks when removing them from the heating device and immersing in the polymer solution.

In the case of elongation at break, the scatter range of the individual tests, but also of the parameter variations, is significantly wider. While the T6 condition of both materials still shows very small deviations in the single-digit percentage range, deviations in the range of 10.9–15.7% occur in the soft annealed state of alloy 7075 in all three parameter variations. Alloy 6082, on the other hand, is stable. The situation is different for the W-Temper. While EN AW-7075 shows maximum deviations of 11.4% in the heating method and 18.9% in the drawing speed, the values for EN AW-6082 vary by up to 56.4%.

In summary, the forming speed has a minor influence on the mechanical properties of the three pretreatments and should therefore be selected as high as possible from an economic point of view. Differences regarding the rolling direction do occur in the case of EN AW-6082-W, but this cannot be influenced in the subsequent forming steps of rotationally symmetrical components. For the soft annealed condition, the heat treatment

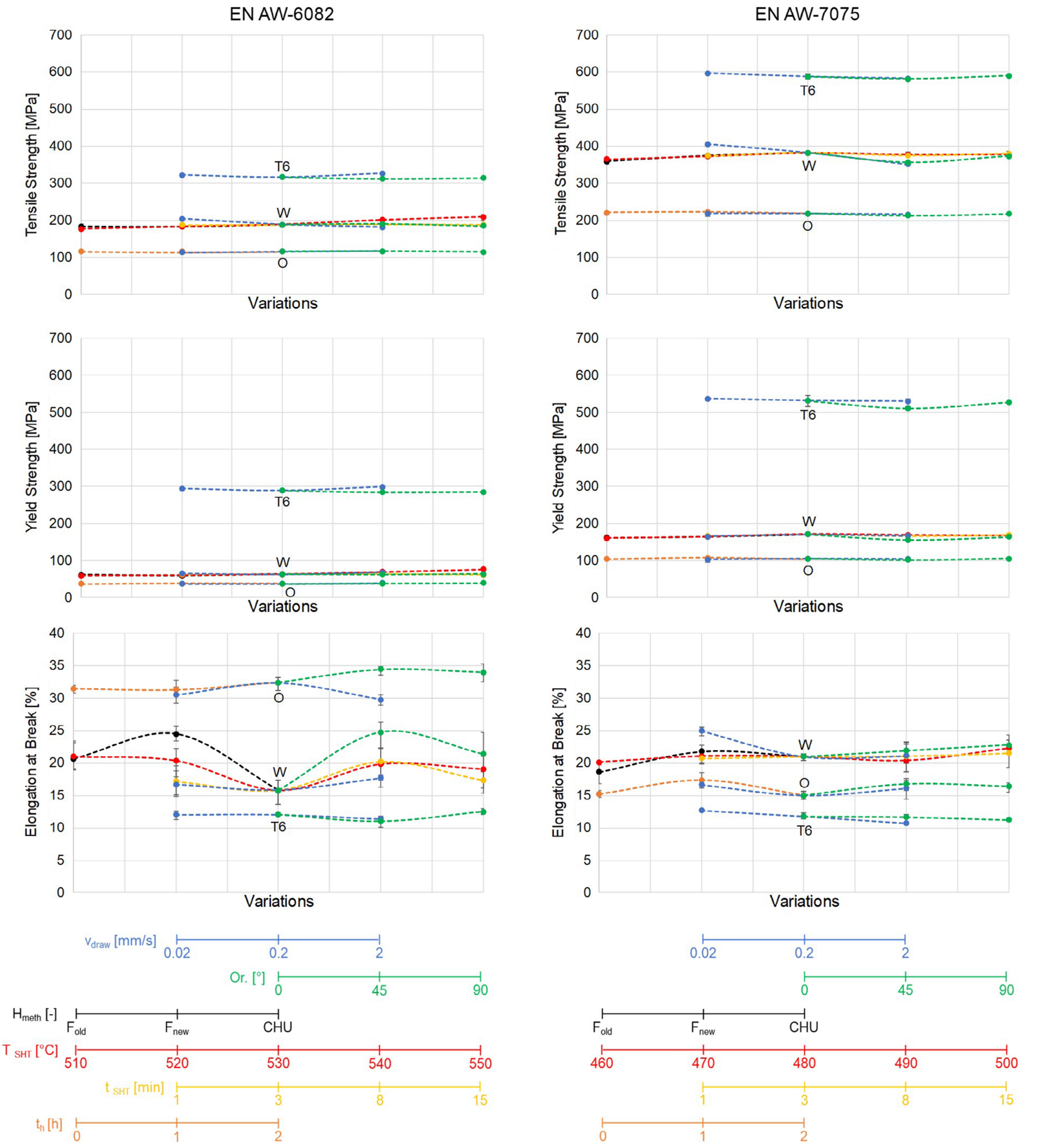

Figure 6. Influencing factors on the mechanical properties of preconditioned semi-finished products of the alloy EN AW-6082 (left) and -7075 (right).

cycle can be shortened by 2 h by reducing or dropping the second holding time, with almost identical material characteristics. The greatest influences in terms of scatter and effect of parameter variation occur in the W-Temper condition. It is noticeable that especially the standard configuration of 6082-W represents a minimum value for elongation at break, whereas all stresses remain at an identical level even with parameter variations. The solution heat treatment temperature and time are of minor importance, but it would be interesting to carry out a parameter variation with the forced convection chamber furnace in further investigations because the W-Temper state produced with it exhibited high elongations at break.

Apart from the elongation at break for the W-condition of 6082, preconditioning to the W- or *O*-state offers a significant improvement in formability with relatively robust process conditions.

4. Forming Behavior

The forming properties of the preconditioned semi-finished products are investigated by means of a four-stage forming tool, which is presented below together with the experimental setup. Subsequently, the forming characteristics are considered first on a single-stage deep-drawing operation and then on a multistage forming process.

4.1. Multistage Forming Tool and Experimental Setup

For producing a demonstrator geometry with a thickened collar, the stadium sequence shown in **Figure 7**a is necessary. It includes the stages deep drawing, blanking, collar drawing, and upsetting and thus combining a wide variety of requirements across the stages to produce such a sophisticated geometry. The four tool stages have an identical basic structure, so that Figure 7c shows an example of the tool design of the first stage. It consists of a spring-loaded blank holder that suppresses wrinkling, a fixed punch of 50 mm diameter, a die that moves through the press stroke, and the spring-loaded ejector.

The blanks with a diameter of 102 mm are inserted by hand into the tool (cf. Figure 7b) and are then transferred quickly and reproducibly between the individual strokes by an electropneumatic transfer system. The press used for this purpose is a servo motor press Synchropress SWP 2500 with a maximum force of 2500 kN. The 100 mm press stroke is covered in 1.2 s. For preconditioning the blanks from the high-strength T6 in the W- or O-state, a N 15/65 forced convection chamber furnace from Nabertherm is used, which ensures fast and homogenous heating. For the experimental investigations, the heat treatments shown in Figure 3 are carried out.

4.2. Single-Stage Process

The investigation of the forming behavior of the preconditioned semi-finished products for a single-stage deep-drawing process is based on the first stage of the presented forming tool. For this purpose, circular blanks with varying diameters from 80 to 120 mm are deep drawn to investigate the process boundaries of the individual states. The fixed drawing depth of 17 mm results in different sized flanges, depending on the initial blank diameter.

The standard blank diameter of 102 mm is formable in five of the six possible material-state combinations, as shown by the green dots in the deep-drawing process window in **Figure 8**. Only the alloy EN AW-7075 in the high-strength T6 state is not formable and breaks into several pieces. Even with a blank diameter of 80 mm, it cannot be formed. In comparison, EN AW-6082 is formable in the T6 condition, although it is also close to the process limit, but this can be significantly extended by means of preconditioning. The alloy EN AW-7075 can also be formed without problems and reproducibly when preconditioned. The preconditioning thus leads to a significant expansion of the formability with a simultaneous reduction in springback.

Any differences in individual parameter combinations could not be detected in the forming experiments. All three conditions proved to be very reproducible.

4.3. Multistage Process

Only the alloy EN AW-6082 in the soft annealed O condition is cold formable across all four stages, as shown in **Figure 9**. All other conditions fail during the expansion through collar drawing in stage 3. These range from slight cracks in the axial direction (EN AW-6082-W) to deep cracks in the axial and circumferential directions (EN AW-7075-W and -O) to fracture

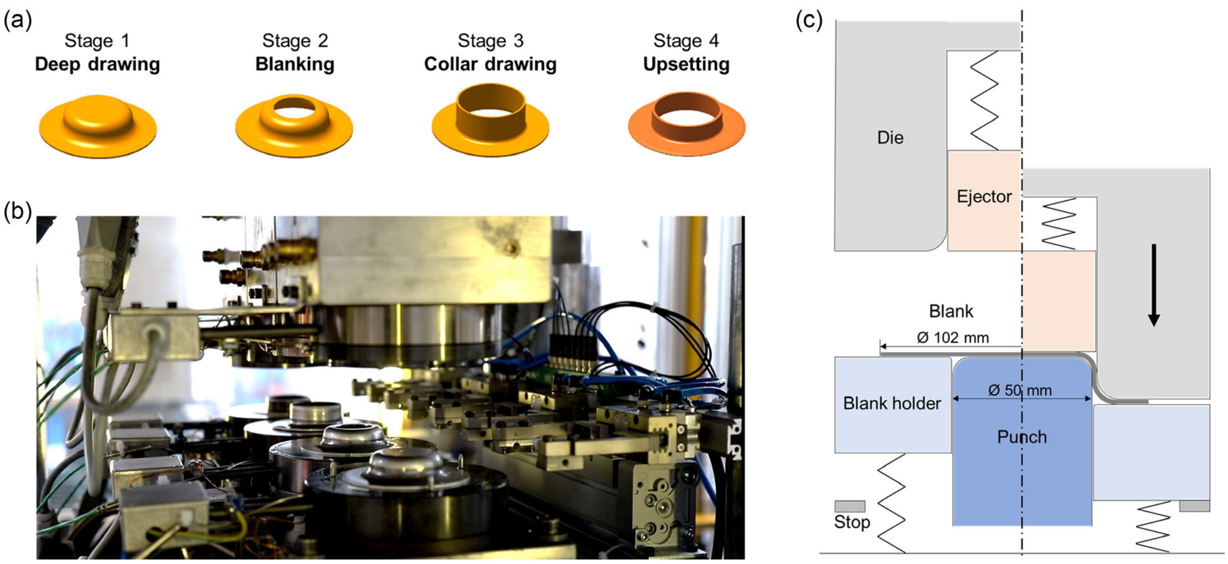

Figure 7. a) Stadium sequence, b) insight into the four-stage transfer tool, and c) schematic tool design of the first stage.

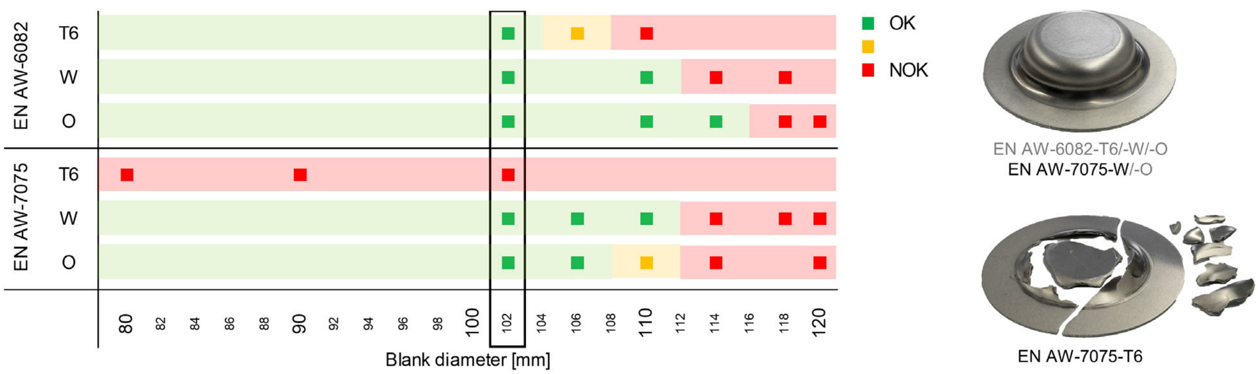

Figure 8. Process limits for deep drawing preconditioned semi-finished products.

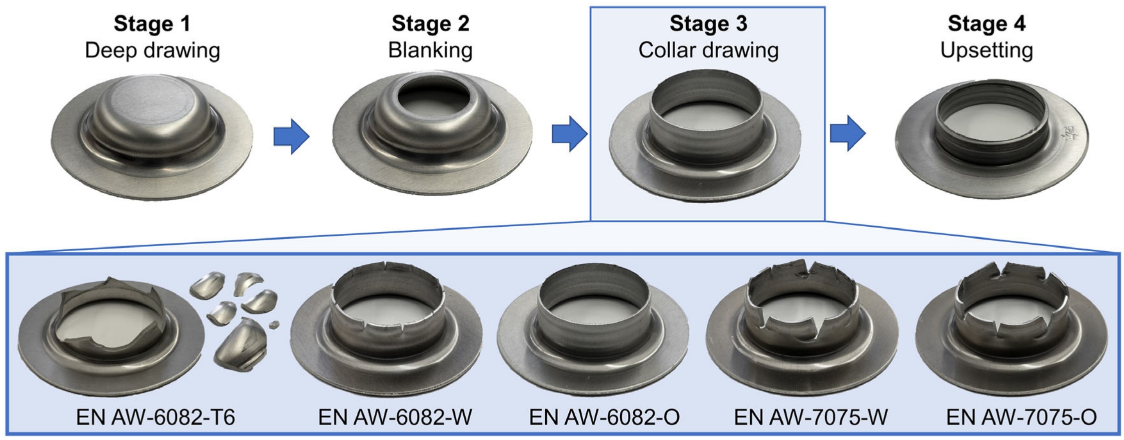

Figure 9. Influence of preconditioning within a multistage forming process.

into several parts in the case of EN AW-6082-T6. The elongations during collar drawing from 32 mm of the hole diameter to the 50 mm punch diameter are accordingly too large.

The hardening effects occurring within the process chain are partly responsible for this. Thus, in addition to the natural aging of the W-Temper condition, strain hardening also takes place as a result of forming as well as blanking, and thus in the zone of the component that is subjected to particular stress, as can be seen in **Figure 10**.

Especially when stamping the alloy EN AW-7075 in the soft annealed O condition, significant hardening effects of almost factor 2 occur in the cutting zone. This restriction on formability in the following stages can be avoided or improved by renewed heat treatment or tempering of the components before forming.[28,30]

5. Subsequent Heat Treatment

To regain the initial properties of the T6 material after forming preconditioned semi-finished products, a subsequent heat treatment is necessary.

For the W-Temper condition, cold aging is not recommended, particularly for the EN AW-7075,[20] as this process can extend over several years.[21] Subsequent heat treatments range from one- or two-stage artificial aging lasting several hours[5,20,21,23] to simple paint bake cycles[25] and combinations of natural aging and paint bake.[10] All of them pursue the goal of the formation of finely divided precipitates and thus to increase the strength.[20] The set cycles differ in terms of temperature from 115 to 190 °C[5,14,20,21,23,25,26] and in terms of time from 20 min up to more than 24 h.[5,10,14,20,21,23,25,26] In addition to the typical influencing variables of time, temperature, and quenching method,[23] the prior plastic strain also influences the resulting properties.[25]

Based on this multitude of possibilities, the following heat treatments are chosen and compared to the original hardness values of the preconditioned semi-finished products (cf. **Figure 11**): 1) natural aging (NA) after one month, 2) artificial aging (AA) for 10 h at 170 °C for EN AW-6082 or 24 h at 120 °C for EN AW-7075, 3) paint bake cycle (PB) (15 min at 125 °C; 25 min at 185 °C; 15 min at 160 °C; 15 min at 150 °C; and 30 min at 140 °C (according to ref. [24])) and 4) precipitation heat treatment (PHT) (solution heat treated, quenched, and artificially aged).

In the W-Temper condition, a significant increase in hardness occurs during natural aging. To achieve a hardness that deviates by ±5% from the initial T6 state, artificial aging is required. If the faster Paint-Bake cycle is used in its place, the hardness increases up to maximum deviations of 12.9% (EN AW-6082) or 8.5%

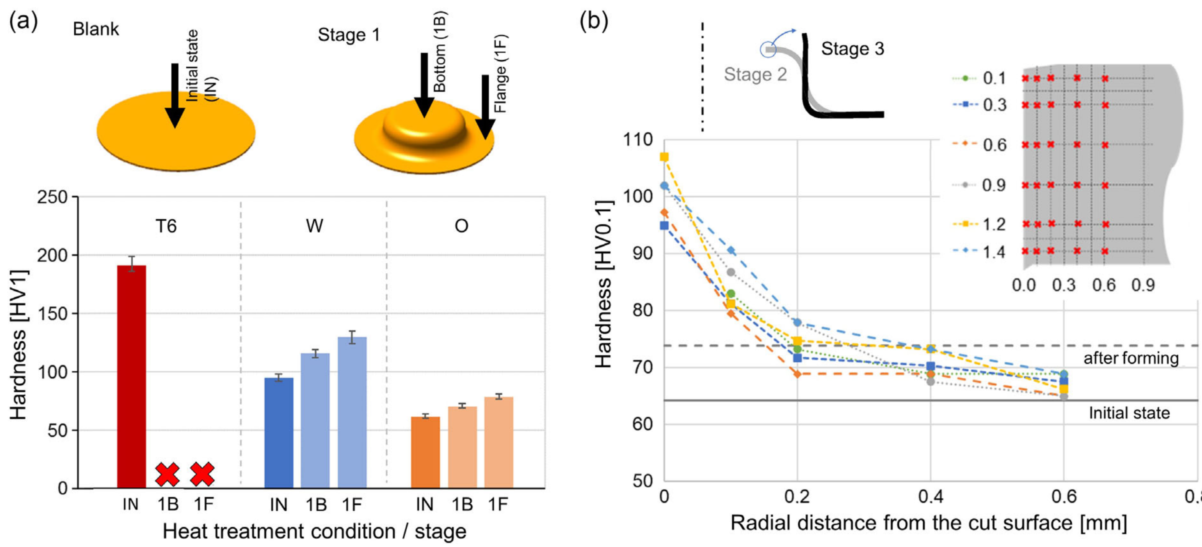

Figure 10. a) Hardening effects of EN AW-7075 in different conditions by forming in stage 1 and of b) EN AW-7075-O through blanking in stage 2.

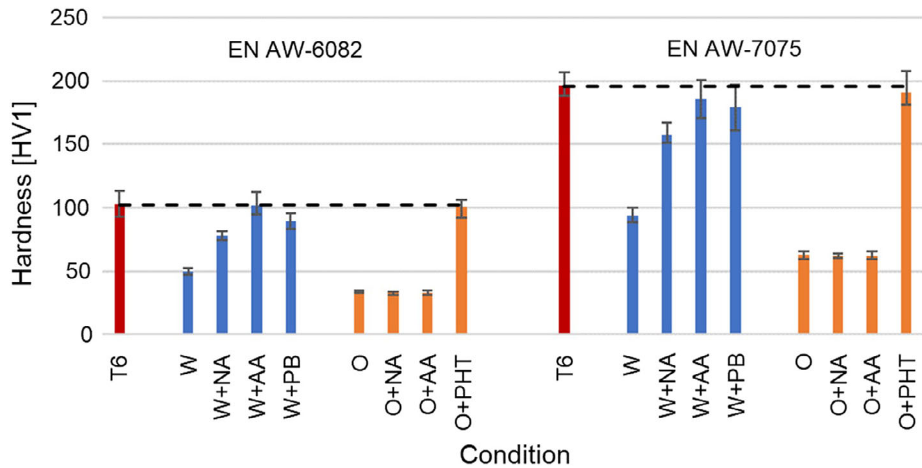

Figure 11. Comparison of hardness values before and after heat treatment for the preconditioned sheets (NA: natural aging, AA: artificial aging, PB: paint Bake, PHT: precipitation heat treatment).

(EN AW-7075) compared to the original T6 state. This is also confirmed by studies of Argandona[5] and Grohmann.[14] In the soft annealed O-state, neither aging process results in any changes, so that a complete precipitation heat treatment is necessary to achieve the initial hardness. Equivalent to the *W* state, a Paint–Bake cycle commonly used in the automotive industry can be applied instead of artificial aging.

Tensile tests of the most promising heat treatments show that the standard values from DIN EN 485-2 are achieved both during the artificial aging of the W-state and the precipitation heat treatment of the O-state. Compared to the initial T6 state, the ultimate tensile strength shows values at a comparable level, while the yield strength is slightly lower and the elongation at break is higher, apart from EN-AW-6082 after forming in the O-state.[6] Based on previous experience and the proportional behavior of hardness and strength, a corresponding transfer behavior to the stress–strain curves is assumed for the Paint–Bake cycle, without having examined this in detail.

6. Conclusion

The work presented in this paper shows that preconditioning of the medium- and high-strength aluminum alloys EN AW-6082 and -7075, both into the W-Temper- and into the O-states, causes a significant influence on the material properties: Forming stresses decrease with a simultaneous increase in elongation, resulting in improved formability. While the 6082 alloy has the highest formability in the O-condition, the W-Temper condition is recommended for the 7075 alloy.

While the process windows for a single-stage deep-drawing process could be significantly extended by preconditioning, hardening effects lead to limitations in multistage forming processes which are required to produce complex components. This can be remedied by renewed heat treatment or by heating the components before critical forming stages.

Compared to the otherwise used process routes of warm or hot forming, in which temperature-controlled tools are used, cold forming of preconditioned semi-finished products enables shorter cycle times and a high reproducibility. The materials also prove to be very robust to fluctuations in the process parameters during preconditioning. The biggest influencing factors result from the quenching method and the natural aging time between preconditioning and forming for the W-Temper.

By means of a suitable subsequent heat treatment, the material can be transferred back to the high-strength T6 state, so that it has a high lightweight potential.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

Research data are not shared.

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formability, heat treatment, high-strength aluminum, mechanical properties, sheet metal forming

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