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Cold Blow Forming of a Thin Sheet in AA8006 Aluminum Alloy

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Thin sheets of aluminum alloys are widely used for the packaging of pharmaceutical and cosmetic products and in the food industry; however, they present critical issues during the forming process. The blow forming process, which is widely used in the glass and plastics industries and for the hot forming of metal sheets, allows solving the problems related to the lubrication and the small tolerance ranges of the tools required by the well-known deep drawing process to form a thin sheet. In this work, the blow forming process is proposed for the first time to cold form thin metal sheets. Its advantage is connected with the use of equipment with a simple shape and, therefore, less expensive. Specifically, this work evaluates the time needed to form a simplified part; this is a critical aspect to apply this forming process to the food packaging industry. Moreover, this process represents the first step to developing a methodology for evaluating the constitutive equation of thin sheets as an alternative to tensile test that has some critical issues connected with specimens' manufacturing and test carrying out.

Keywords: food packaging; free forming test; cold forming; thin sheet; AA8006 aluminum alloy

1 Introduction

Aluminum alloys are widely used due to their peculiar properties. They have excellent formability and workability [1]; they can be easily painted and lacquered; they do not present problems of toxicity and contamination [2]. For these reasons, they are often used for the packaging of pharmaceutical and cosmetic products or in the food industry [3]. The containers in aluminum allow for storing food away from light, oxidation, and more generally from the external environment. Moreover, the surface of the aluminum sheets has excellent hygienic properties because, being non-absorbent, it can be easily cleaned and sterilized [4,5]. Finally, aluminum foil is an environmentally sustainable product, because it is constituted of a recyclable material [6,7].

Aluminum sheets, whose thickness ranges from 6 microns to 160 microns, are used for food packaging [8,9]. The thinnest sheets are sold in the form of rolls or they are used to stamp semi-rigid wrinkle wall containers [4], while thicker sheets are used to stamp stiffer smooth wall containers. The latter type of container is very interesting for the food packaging industry because a transparent organic film is applied to them to produce airtight containers in a vacuum sterilized environment [10]. In this way, it is possible to sell food ready for use inside a container that allows it to be viewed by the end customer [11].

Nowadays, the manufacturing of aluminum smooth wall containers for food packaging is carried out through deep drawing processes. However, the use of very thin sheets requires a very small roughness of the dies, the use of special lubricants suitable to come into contact with food, and accurate control of the forces during the process [12].

In this work, an innovative approach to manufacturing smooth wall containers for food use is proposed. In detail, the use of the blow forming process to shape thin sheets at room temperature is deeply discussed.

Blow forming is widely used to manufacture hollow products in plastic or glass (for example bottles or flacons) [13]. It uses compressed air that is sent inside a heated preform placed inside a hollow die. The air pushes the sheet into contact with the die walls. Once formed and cooled, the part is removed from the die.

Pressurized air or gas can also be replaced by the use of a vacuum pump. For example, in the thermoforming process vacuum is used to form sheets of thermoplastic material placed over a die. In detail, once the sheet is heated in an oven up to the sagging temperature, it is hermetically placed on a die and formed using the vacuum produced between the die and the sheet. In this case, forming can be eased using pressurized air or gas as in blow forming [14,15].

Pressurized gas is used in sheet metal forming [16-17] and in superplastic forming of aluminum, magnesium, lead, and titanium alloys [18-21]. However, the manufactured products are for aeronautics, automotive, and aerospace applications. This process is used to manufacture in a single step strong and light parts [22,23]. To this end, the sheets to form have thicknesses of millimeters or more.

Stamping of aluminium thin sheets requires the knowledge of how the material behaves during forming in dependence on its thickness; the deformation mechanisms that are inside thin sheets during stamping are different from those inside a bulk submitted to the same process. Generally, as the thickness of the sheet decreases, the formability of the material decreases [24]. Therefore, tensile tests must be performed to mechanically characterize the material, paying particular attention to the specimens' manufacturing and the test carried out [25,26].

In the field of food packaging, the use of the blow forming process at room temperature solves the critical issues related to lubrication and the small tolerance ranges required by the tools of the well-known deep drawing process. Moreover, the equipment required for the process has a simpler shape and, therefore, is less expensive.

In this work, the blow forming process is proposed for the first time to cold form thin metal sheets. Its advantage is connected with the use of equipment with a simpler shape and, therefore, less expensive. In detail, this work evaluates the time needed to form a simplified part; this is a critical aspect to apply this forming process to the food packaging industry. Moreover, this process represents the first step to developing a methodology for evaluating the constitutive equation of thin sheets as an alternative to tensile test that has some critical issues connected with specimens' manufacturing and test carrying out. The aim of this work is a purely technological analysis to evaluate the processability of AA 8006 thin sheets with blow forming process of at room temperature. Chemical and microstructural analysis can be carried out in future works.

2 Material and methods

The material used in this work is the EN AW 8006 aluminum alloy, which is commercially available in the form of sheets. It contains small percentages by weight of Fe (1.2-2.0%), Si (0.4%), Cu (0.3 %), Mn (0.3-1.0%), Mg (0.1%) and Zn (0.1%). It has a low density (2.74 g / cm^3), a mechanical strength between 110 and 150 MPa, and good corrosion resistance. It is widely used in the packaging industry (to manufacture food containers) because it protects food from contact with light, air, humidity, and bacteria; in this way it preserves food's original taste, once sealed, by making it last longer. Moreover, it can be recycled and reused efficiently.

The experimental tests were carried out by applying the blow forming process to circular discs with a 40 mm radius and a 105 μm thickness. The free-forming tests were performed using the experimental equipment presented in [27]. Fig. 1 shows the three steps of the free-forming process.

a) b) c)

Fig. 1 *The three steps of the free-forming process: a)specimen placement; b)die closing; c)opening of the compressed air injection valve*

The equipment consists of a two-part die. The lower part of the die has a cavity in which air pressurized by a compressor enters using a butterfly valve. The upper part of the die acts as a blank holder, it keeps the edges of the sheet in contact with the lower die during the forming process using four holes. The pressure of the air coming from the compressor is regulated using a proportional valve. At the end of the forming process, the height reached by the bulging dome and the thickness at its apex are measured.

Cold free-forming tests were carried out at forming pressures of 0.3, 0.4, and 0.5 MPa.

Preliminary tests showed that opening the valve instantaneously to bring the specimen quickly to the process pressure causes the specimen to break, with a consequent pressure drop in the die due to the release of compressed air. To overcome this problem, the forming pressure was reached through several intermediate steps. In detail, during the test, the air pressure was increased by 0.05 MPa every 30 seconds until the wanted value of pressure is reached. Therefore, the wanted value of pressure is kept constant for some time (called holding time). In this way, it was possible to form dome without breaking them.

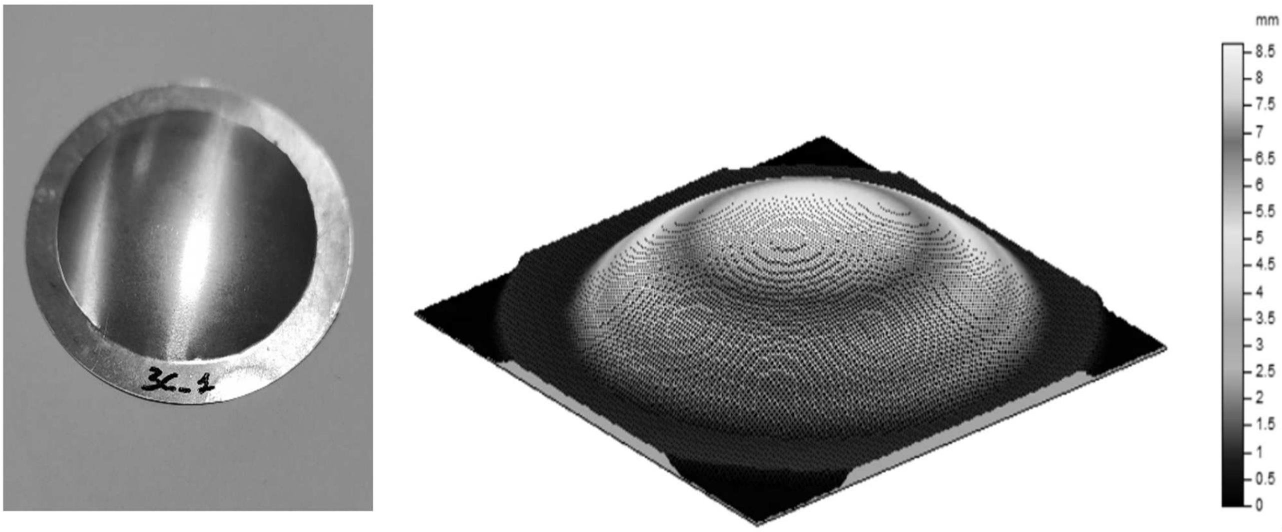
The holding time varied from 1 minute to 10 minutes; the following values were considered: 1, 2, 4, 6, and 10 minutes. Three repetitions were carried out for each combination of pressure and holding time values.

The height of the manufactured hemispheres was measured through Conoscan 3000 equipment by Optimet®; it is a 3D scanning system based on a conoscopic holography device with a repeatability of 0.4 μm and an absolute accuracy lower than 0.3 μm.

The measurement of the thickness at the apex of the bulged dome was carried out by Magna-Mike 8600 of Olympus®, it is a portable thickness gauge that uses a simple magnetic method to make measurements on nonferrous materials. Measurements were carried out by placing the sheet between the magnetic probe and a small steel target ball of 3.175 mm diameter. The instrument allows measuring thicknesses between 0.001 mm and 6.1 mm with a measurement tolerance lower than 0.005 mm. For each dome, three thickness measurements at the apex were made. 45 samples were formed and for each forming condition 3 replicates were considered, so 15 combinations of forming pressure/holding time values were considered. Three levels of the forming pressures were adopted: 0.3MPa, 0.4MPa and 0.5MPa. Five dwell times were considered: 1 min, 2 min, 4min, 6 min and 10 min. In this way, it was possible to evaluate the effect of the holding time over a reasonably long period for the manufacturing process under consideration.

3 Results and discussion

The experimental results showed that it is possible to cold form thin sheets in AA8006 aluminum. Fig. 2a shows a dome bulged with a pressure of 0.3MPa, while its shape obtained by the 3D scanning through Conoscan 3000 is reported in Fig. 2b. It can be observed that the reached maximum height is about 8.1mm.



a) b)

Fig. 2 *Hemisphere manufactured with a pressure of 0.3 MPa by blow forming process: a) Bulged dome; b) 3D scanning of the hemisphere to evaluate its height*

Fig. 3 shows the measured thickness values at the apex of the formed dome. The measured values showed that the thickness values at the apex do not depend on the holding time, but only on the forming pressure. For this reason, in order to facilitate the reading of the graph, Fig. 3 shows the thickness values at the apex as a function only of the forming pressure. In particular, for each forming pressure, 15 specimens were tested according to the experimental plan discussed in the material and method section. On the axis of the ordinates, the average value of the thickness values measured at the apex of the dome for each used pressure value is shown. The average was carried out on 15 samples (three replicates for each of the five considered holding time values). As expected, the average value of the thickness at the apex decreases with the increase of the forming pressure [21].

Tab. 1 shows the average values of the dome height for different values of pressure and holding time. It is possible to state that the proposed process has a high repeatability in terms of dome height for each process condition because thecoefficient of variation is ever lower than 2%. Moreover, the effect of the holding time on the height of the formed domes appeared negligible. In fact, in the case of domes formed at 0.3 MPa, the height variation between the higher and the lower holding time was 4.9%, while in the case of domes formed at 0.4 MPa and 0.5 MPa was respectively 3.8% and 4.5%.

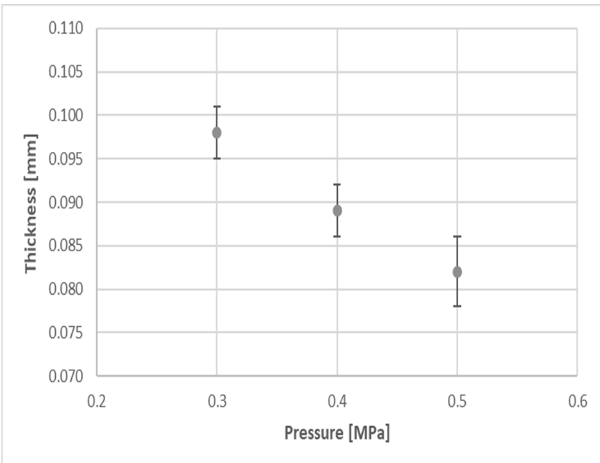


Fig. 3 *Thickness values at the apex of the bulged domes vs adopted pressure values*

Tab. 1 *Average values of bulge dome height*

Forming pressure [MPa]	Holding time [min]	Experimental height average values [mm]	Experimental standard deviation [mm]	Coefficient of variation
0.3	1	8.05	0.08	0.99%
0.3	2	8.06	0.09	1.12%
0.3	4	8.09	0.07	0.87%
0.3	6	8.16	0.11	1.35%
0.3	10	8.39	0.13	1.55%
0.4	1	10.40	0.1	0.96%
0.4	2	10.47	0.17	1.62%
0.4	4	10.57	0.15	1.42%
0.4	6	10.78	0.18	1.67%
0.4	10	10.83	0.19	1.75%
0.5	1	14.18	0.13	0.92%
0.5	2	14.25	0.18	1.26%
0.5	4	14.60	0.14	0.96%
0.5	6	14.68	0.22	1.50%
0.5	10	14.83	0.20	1.35%

It is possible to see that the average value of the bulged dome height tends to increase as the forming pressure or the holding time increases. Taking into account that the height value reached with a holding time of 10 min is only 5% higher than that due to a holding time of 1 min, it is possible to state that the effect of the holding time is negligible inside the considered range. This is because the forming temperature (T) is much lower than the melting temperature (T_m) of the material:

$$\frac{T}{T_m} \leq 0.3 \div 0.4 \tag{1}$$

At this temperature, the metal strain hardening affects the process instead of the strain rate [1]. The use of temperatures above room temperature would lead to greater formability of the material but also to a greater influence of the holding time on the height of the formed dome. In this case, the evaluation of the strain mechanisms should also be evaluated for a complete understanding of the material's behaviour as a function of time and temperature. In the case of forming at room temperature, the investigated material complies with Eq.(1), so its formability depends only on its hardening behaviour, which is a function only of the forming pressure. The thicknesses value at the apex of the bulged domes shows a relationship with forming pressure that is inverse to that of the dome height, [19]. In fact, as the forming pressure increases, the thickness at the apex of the dome decreases [18]. This is due to the increase of the part surface free from contact with the die during forming.

4 Conclusions

The work shows how the blow forming process may cold form thin sheets in AA8006 aluminum alloy. This process replaces the punch of the well-known deep drawing process with pressurized air. In this way, the involved equipment has a simpler shape and, therefore, is less expensive. The experimental activity, that was carried out in this work, showed that it is possible to use the blow forming process to shape thin sheets. It underlined that the holding time does not affect the height of the bulged domes, once the process pressure was reached. Moreover, as the forming pressure increases, the height of the dome increases while the thickness at the apex decreases. The possibility of forming the material at a homologous temperature below 0.3 revealed a negligible influence of the holding time on the height of the formed specimens. This aspect allows optimizing the forming times without affecting the geometry and dimensions of the formed part. Moreover, the process showed an high repeatability in terms of dome height for each process condition becausethe coefficient of variation is ever lower than 2%.

A further development of blow forming is its use to evaluate the constitutive equation of thin sheets instead of the tensile test that has some critical issues connected with specimens' manufacturing and test carrying out. Blow forming allows taking into account the stresses and strains generated by a forming process inside a complex shaped part better than a tensile test does. Future works will investigate the effects of the process on the microstructure of the AA 8006 thin sheets.

References

[1] GIULIANO G, POLINI W. Weight reduction in an AA2017 aluminum alloy part through the gas forming process of a blank with a variable thickness. *Manufacturing Technology* 2021; 21,2, 192-198.

[2] ERTL K, GOESSLER W. Aluminium in foodstuff and the influence of aluminium foil used for food preparation or short time storage. *Food Additives & Contaminants*: Part B 2018;11,2:153–159.

[3] FÁVARO SL, FREITAS AR, GANZERLI TA, PEREIRA AGB, CARDOZO AL, BARON O, et al. PET and aluminum recycling from multilayer food packaging using supercritical ethanol. *The Journal of Supercritical Fluids* 2013;75:138–43.

[4] KERRY J. Aluminium foil packaging. Packaging Technology, *Elsevier*; 2012, p. 163–177.

[5] SAADI N, ALOTAIBI K, HASSAN L, SMITH Q, WATANABE F, KHAN AA, et al. Enhancing the antibacterial efficacy of aluminum foil by nanostructuring its surface using hot water treatment. *Nanotechnology* 2021; 19:32(32)32.

[6] GALLEGO-SCHMID A, MENDOZA JMF, AZAPAGIC A. Environmental impacts of takeaway food containers. *Journal of Cleaner Production* 2019; 211:417–427.

[7] GHOSH P, WESTHOFF P, DEBNATH D. Chapter 12 - Biofuels, food security, and sustainability. In: Debnath D, Babu SC, editors. Biofuels, Bioenergy and Food Security, *Academic Press*; 2019; 211–229.

[8] GISARIO A, AVERSA C, BARLETTA M, NATALI S, VENIALI F. Laser joining of aluminum film coated with vinylic resin and plastic/bioplastic films for applications in food packaging. *Optics & Laser Technology* 2021;142.

[9] VIGNESHWARAN K, VENKATESHWARAN N, DHANARAJ R. Mechanical and Mode I fracture toughness characteristics of hybrid laminated composites. In: Khan A, Rangappa SM, Siengchin S, Jawaid M, Asiri AM, editors. Hybrid Natural Fiber Composites, *Elsevier*; 2021; 207–223.

[10] MONETTA T, ACQUESTA A, BELLUCCI F. A multifactor approach to evaluate the sealing of "smooth-wall" containers for food packaging. *Surface and Coatings Technology* 2017;310:33–37.

[11] STRULLER C, KELLY P, COPELAND N. Conversion of aluminium oxide coated films for food packaging applications—From a single layer material to a complete pouch. *Food Packaging and Shelf Life* 2019;20.

[12] MAHMOODI P, ELREFAEY A, HASSAN OI, MORGAN HD, SIENZ J, BELBLIDIA F. Towards a wickless smooth–Wall aluminium food packaging tray mould tool digital twin - Advanced computational modelling supported by experimental validation. *Applied Mathematical Modelling* 2022;105:375–386.

[13] BELCHER SL. BLOW MOLDING. In: Kutz M, editor. Applied Plastics Engineering Handbook, *Elsevier*; 2017; 265–289.

[14] SCHMIDT FM, LE MAOULT Y, MONTEIX S. Modelling of infrared heating of thermoplastic sheet used in thermoforming process. *Journal of Materials Processing Technology* 2003;143–144:225–231.

[15] WARBY MK, WHITEMAN JR, JIANG WG, WARWICK P, WRIGHT T. Finite element simulation of thermoforming processes for polymer sheets. *Mathematics and Computers in Simulation* 2003;61:209–218.

[16] GIULIANO G. Gas blow forming multiphase process using a non-superplastic material. *Journal of Manufacturing Technology Research* 2018; 10, 1-2: 81-88.

[17] GIULIANO G, CORRADO A, POLINI W. On the gas blow forming multiphase process of an AA5083 aluminium alloy sheet. *Journal of Manufacturing Technology Research* 2019; 11, 1-2:1-11.

[18] GIULIANO G. Superplastic forming of advanced metallic materials. *Woodhead Publishing Limited*; 2011.

[19] GIULIANO G. On the constitutive equation of AA2017 aluminium alloy at high temperature. *Manufacturing Letters* 2016;10:10–13.

[20] GIULIANO G, CORRADO A, POLINI W. Influence of multiphase forming approach on the thickness uniformity of components from superplastic PbSn60 alloy. *Manufacturing Letters* 2018;18:16–19.

[21] GIULIANO G, POLINI W. Influence of blank variable thickness on the material formability in hot gas sheet metal forming process. *Manufacturing Letters* 2020; 24:72–76.

[22] YU H, CUI X. Rolling forming of multi-scaled metallic foils and sheets. In: Caballero FG, editor. Encyclopedia of Materials: Metals and Alloys, *Oxford: Elsevier*; 2022, p. 160–181.

[23] FARAJI G, KIM HS, KASHI HT. Applications of ultrafine-grained and nanograined metals. In: Faraji G, Kim HS, Kashi HT, editors. Severe Plastic Deformation, *Elsevier*; 2018, p. 275–306.

[24] CHANG TA, RAZALI AR, ZAINUDIN NAI, YAP WL. Size effects in thin sheet metal forming. IOP Conference Series: *Materials Science and Engineering* 2015;100(1):012051.

[25] TROST COW, WURSTER S, FREITAG C, STEINBERGER A, CORDILL MJ. A new approach to evaluate the elastic modulus of metallic foils. *Materials & Design* 2020;196:109149.

[26] PANDEY AK, DATE PP. Mechanical and micro-structural characterization of hot rolled brass foil. *Materials Characterization* 2021;181:111515.

[27] GIOVINCO G, GIULIANO G, TESTA G. Forming Apparatus to Investigate the Effect of Temperature on the Superplastic Behaviour of Alloys. *AIP Conference Proceedings*, 2010; 1252: 304–11.