Experimental Characterization of Coated Aluminum Sheets for Deep Drawing Applications

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Abstract. Sheet metal forming is widely used in many industries, especially in manufacturing automotive body parts and white goods. For many years, coated kitchen utensils are being used because of their properties such as non-stick property. The most used coating is polytetrafluoroethylene (PTFE), known as Teflon. Kitchen utensils are mainly manufactured by deep drawing processes, which require a good knowledge of the behaviour and the formability of the material. To characterize the formability of the sheets, it is necessary to determine the forming limit diagram (FLD). The FLD can be obtained throughout different essays such as Marciniack test and Nakazima test. With the FLD it is possible to compare the formability of different materials. Also, knowing the FLD can reduce the process' development time. In this work, aluminium sheets coated with Teflon are studied experimentally. Firstly, dilatometer and tensile tests were carried out to investigate the thermal and the mechanical properties of the coated sheets. Furthermore, Nakazima test was conducted to obtain the forming limit diagram (FLD) of the studied material. Also, a numerical approach based on the Finite Element Method (FEM) is being developed to determine the limit of the considered deep drawing process.

Keywords: Coated aluminum sheet · Formability · Deep drawing · Nakazima test · FLD · FEM

1 Introduction

The industry of coated kitchen utensil has rapidly increased in the last decades. Their non-stick property is one of the most wanted properties by consumers. The polytetrafluoroethylene (PTFE), known as Teflon, has been used as a coating material for cookware since the 1950s.

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Drawing and deep drawing are the most common ways of manufacturing cookware. The manufacturing of polymer coated cookware is mainly done by drawing and deep drawing. In some industrial applications, the coating is applied after the forming of the sheet metal. This process is used especially for low ductility coating like ceramic coatings. However, using coated metal sheets was proven to have better results. Erdin and Ozdilli [1] compared the deep drawing of polymer coated and uncoated metal sheets. The results showed that the surface roughness is reduced when using coated metal sheets, which reduced friction during deep drawing and increased mold life. Furthermore, the deep drawing ratio increased from 2.13 to 2.33 and the average molding force was reduced.

Before deep drawing, it is important to know the limits of formability of the coated sheet metal. The forming limit diagram (FLD) is the most used mean to characterize the formability. Nakazima tests are used to obtain the FLDs. Researchers have compared the results of the forming limit diagrams of GI steel and vinyl coated metal (VCM) obtained by Nakazima dome test simulations [2]. They found that the formability of VCM was lower compared to GI steel. Keeler [3] and Goodwin [4] were the first to investigate the formability of sheet metals.

In literature we can find different papers dealing with metal sheet forming [5–9]. Numerical modelling is being more and more used nowadays. Many studies were carried out to investigate numerically the formability of metal sheets [10–12]. However, the resources about Teflon coated aluminium sheets are not common to find. Since Teflon is the most used coating for cookware utensils, it is important to characterize the mechanical properties of Teflon coated aluminium sheets. In this paper, aluminium sheets coated with Teflon are studied. Nakazima test was experimentally conducted to obtain the forming limit diagram (FLD) of the studied material. Furthermore, dilatometer test and tensile test were carried out to investigate the mechanical properties of the coated sheets. The results of this paper will be used for further research work.

2 Experiment and Method

To determine the mechanical properties of the Teflon coated aluminium sheets, tensile and dilatometer tests were carried out. To obtain the forming limit diagram of the studied material, Nakazima test, according to DIN EN ISO 120042 [13], was experimentally conducted. Also, the deep drawing process is numerically investigated using the finite element software Abaqus.

2.1 Material

In this paper, Al 1050 sheets coated with a thin layer of PTFE are considered. The coating is applied on both sides of the sheets. Table 1 presents the chemical proportions (%) of Al 1050.

Table 1. The chemical proportions (%) of Al 1050

	Al	Fe	Si	Cu	Mn	Mg	Zn	Ti
Al 1050	99.5	0.4	0.25	0.05	0.05	0.05	0.07	0.05

2.2 Experimental Tests

2.2.1 Dilatometry

Dilatometer tests were performed on Dil805A/D+T machine shown in Fig. 1 below. Inductive heating method is used for the test. Two thermocouples ensured the measurement of temperature of the specimens.

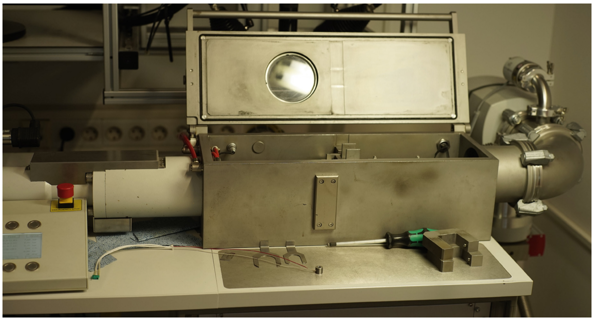

Fig. 1. Dilatometer machine

All the samples were heated to 180 °C so that no damage occurred to the coating. Six samples were investigated in this study. They had been heated to 180 °C and then cooled to room temperature with variation of the temperature speed.

The experimental parameters for the different specimens are presented in Table 2.

Table 2. Temperature speed for dilatometer test

	Temperature speed (K/s)	
	Heating	Cooling
1	1	0.5
2	1	0.5 (with gas)
3	3	1
4	5	1
5	7	1.5 (with gas)
6	7	3 (with gas)

2.2.2 Tensile Test

The tensile test was operated on DynaMess S100/ZD machine. The maximum pulling speed that the machine can reach is 5m/s. The test was conducted in room temperature according to DIN EN ISO 68921 [14]. Rectangular samples of 2 mm thickness were used five repetitions of the test were conducted to ensure the reliability of the results.

The tests were performed with a constant velocity of 5 mm/min. The stress-strain curves are directly obtained using Aramis software. The specimens' geometries for dilatometer and tensile tests are shown in Fig. 2.

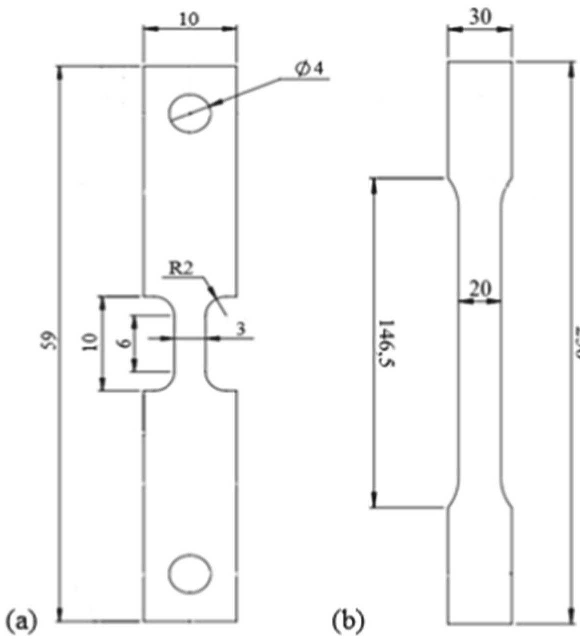

Fig. 2. Specimens' geometries

2.2.3 Nakazima Test

For Nakazima test, the specimens' geometries and experimental set-up were prepared according to DIN EN ISO 12004-2 [13, 15]. Figures 3 and 4 illustrates, respectively, the schematic and the experimental setup according to Nakazima test. Six different specimen widths were used to obtain the whole domain of the FLC [16]. The tests were performed until fracture occurred on the aluminium sheet.

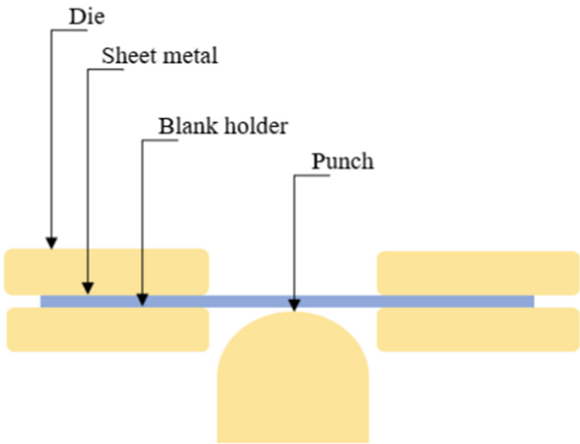

Fig. 3. Schematic Nakazima's test setup

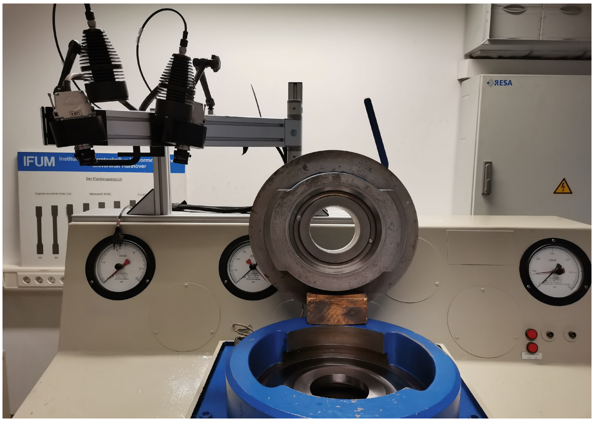

Fig. 4. Experimental Nakazima's test setup

3 Results and Discussion

To evaluate the mechanical properties of Teflon coated aluminium sheets, dilatometer tests, tensile tests and Nakazima tests were experimentally conducted.

First, the linear thermal expansion coefficient α was investigated throughout the dilatometer test. This coefficient was calculated with the expression [17]

$$\alpha = \Delta L/(L.\Delta T) \quad (1)$$

in which ΔL and ΔT represents respectively the length and the temperature variations.

The results showed that the average linear thermal expansion coefficient is about 1.9 e−05 K^{-1} (standard deviation: S.D: 1e−06).

To evaluate the mechanical properties of the Teflon coated aluminium sheets, tensile test was performed. The engineering stress-strain curves of the five specimens, shown in Fig. 5, were then obtained.

The yield strength (YS) and the ultimate tensile strength (UTS) were determined for each specimen. The average results were YS = 57.5 (S.D: 1.2) MPa and UTS = 106.2 MPa (S.D: 0.7).

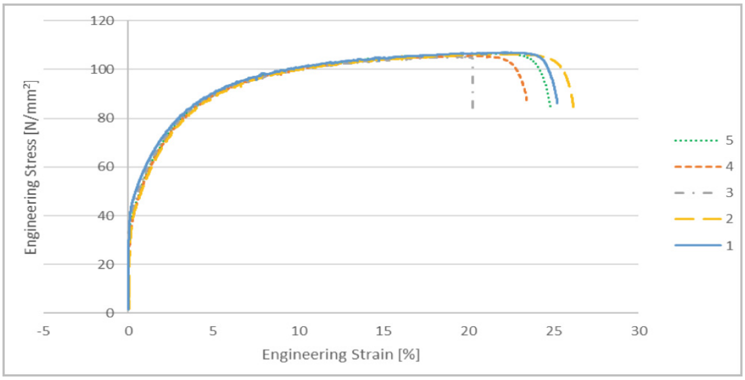

Fig. 5. Engineering stress-strain curves

The true stress and strain values were then, respectively, calculated using the next two formulas:

$$\sigma = R(1+e) \tag{2'}$$

and

$$\varepsilon = \ln(1+e) \tag{3}$$

where R is the engineering stress and e represents the thickness of the specimen. Figure 6 shows the true stress-strain curve. This curve will be used when modelling the problem with finite element method.

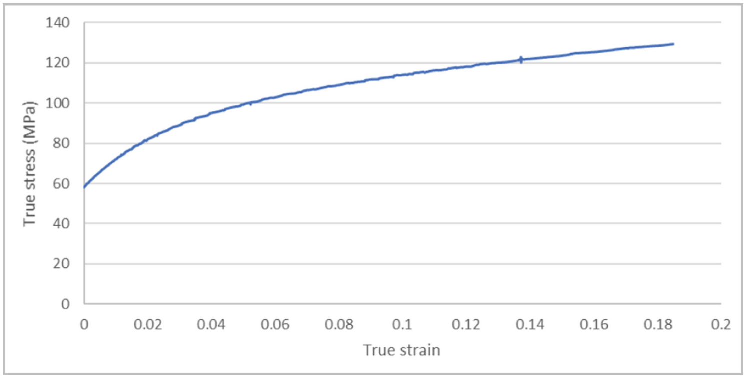

Fig. 6. True stress-strain curve

To study the formability of the coated aluminium sheets, Nakazima tests were carried out. The establishment of the FLD for Teflon coated aluminium sheets is very important as it provides information about the formability of the material and, therefore, knowing the working zone when performing deep drawing. While conducting the test, major strains and minor strains are being measured with the optical measuring system ARAMIS. The test was conducted until fracture occurs in the aluminium sheet, as shown in Fig. 7. The determined FLD for the investigated material is represented in Fig. 8. As can be seen, the minimum values of the major strain are obtained for values close to 0.1 of the minor strain. Furthermore, the results can be compared to the FLDs of uncoated aluminium sheets, and so deduct the influence of the coating on formability. Researchers determined the FLD of uncoated Al1050 sheets and with different thickness [15]. Comparing the results of coated and uncoated aluminium sheets, the coated sheets had better formability.

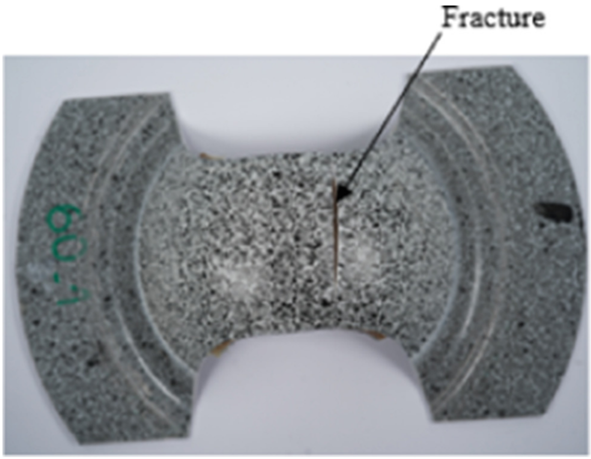

Fig. 7. Fracture in Nakazima test

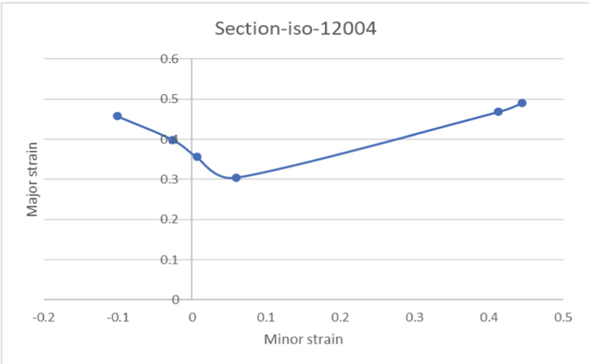

Fig. 8. Formability limit diagram

The obtained FLD will be used in later research work to be compared with the formability of aluminium sheets coated with different types of hybrid coatings.

4 Conclusion and Perspective

In this paper, PTFE coated aluminium sheets were studied. Experimental tests were conducted to determine the mechanical properties and the formability of the investigated material. The linear thermal expansion coefficient was obtained throughout the dilatometer test. Also, tensile test was performed to determine some mechanical properties of the studied material. As far as the formability, Nakazima test was carried out. Throughout this test, we were able to establish the forming limit curve. The aim of this study is to determine some properties, especially the formability, of Teflon coated aluminium sheets. The obtained results are to be used in further works.

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