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BENDING FORCE AND SPRINGBACK CHARACTERISTICS OF THE TAILOR-WELDED 18G2A-E355 STEEL STRIPS

In many studies a wide range of information about the bendability, failure patterns and the springback of homogeneous as well as tailor-welded sheet metal parts are presented. However, accurate prediction of the springback remains elusive, especially in the case of thick sheet metal. The purpose of this study was experimental determination of the bending force and springback coefficient of the tailor-welded 18G2A-E355 steel strips. Especially, it was focused on comparing the differences in the mechanical properties and bending characteristics between the tailor-welded strips and non-welded ones under the same experimental conditions. The set-up mounted on the testing machine, instrumentation and process control system allows the rig to operate in displacement as well as load control. The MAG method with the Argon + CO_2 atmosphere was used for strips welding.

Keywords: tailor-welded sheet metal, strain hardening, bending force, springback

1. Introduction

Bending is one of major sheet and strips forming operations widely used in modern industries. For this reason, understanding the bending process helps to provide some information crucial to industrial production. Recently many industry companies are trying to form different products by using tailor-welded blanks. A tailor-welded blank consists of two or more sheets that have been welded together in a single plane prior to forming. And the sheets joined by welding can be identical, or they can have different thickness, mechanical properties or surface coatings. Various welding processes, i.e. laser welding, mash welding, electron-beam welding or induction welding, can join them.

In the field of sheet metal bending, one can find literature on pure bending, V-die bending, simple flanging and so on. Most materials can be bent to quite a small radius, but a problem is to control the shape of the bend workpiece. In general, a bend workpiece will recover elasticity i.e. springback on unloading, so that the bend quality is heavily dependent on the springback, which is a function of material properties and process parameters such as Young's modulus, yield stress, strain hardening abilities, plastic anisotropy, thickness and die geometry [1-6]. The most important die bending process is bending in a V-shaped die, so that deformed shape results from the sheet being pressed into the die by the punch until it is in contact with the sides of the die to the maximum extent possible.

Springback is a phenomenon in which the metal strip unbends itself after a forming operation. Control of springback for the bending processes applied in practice is difficult for a number of reasons, especially in mass production [2, 7-12]. In the case of tailor-welded strips the quality of the weld is critical for a successful forming operation [13, 14] and affects springback phenomenon [15, 16]. Sheet metal forming processes, such as bending, stretching and drawing are widely applied industrially, but design of tools and selection of sheet material remain almost invariably dependent on trial and error [8]. The main reason is that the shape of tools, characteristics of material, process variables and the geometric configuration of the workpiece all influence the manufacturing process: these characteristics are difficult to formulate into a precise mathematical model. The evaluation of elastic springback effects is a fundamental aspect in the practice of sheet forming operations. Springback, in fact, introduces deviations from the desired final shape – consequently, the stamped sheet does not conform to the design specifications and could result in being unsuitable for the application. A complete knowledge of the springback phenomenon and its dependence on material and process variables is strongly required in order to develop effective real time process control systems.

The main purpose of this study was experimental determination of the bending force and springback coefficient of the tailor-welded 18G2A-E355 steel strips. Especially, it was focused on comparing the differences of the mechanical properties and bending characteristics between the tailor-welded strips and non-welded ones under the same experimental conditions.

2. Experimental materials and methods

The 18G2A-E355 steel strips, 9.0 mm thick were used in this experiment. The MAG method with the Argon + CO_2 atmosphere was used for strips welding. Geometry of strip edge prepared for welding is presented in Fig. 1. When the mechanical testing is concerned, 3 types of tensile specimens (Fig. 2) of 240 mm gauge length and 12.5 mm width in gauge region were prepared from:

- based material strip,
- strip containing longitudinal weld,
- strip containing transverse weld.

The experiments were carried out using a special device, which recorded simultaneously the tensile load, the current length of the specimens.

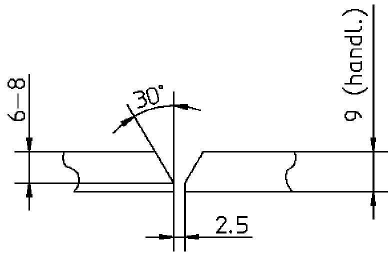

Fig. 1. Geometry of strip edge prepared for welding

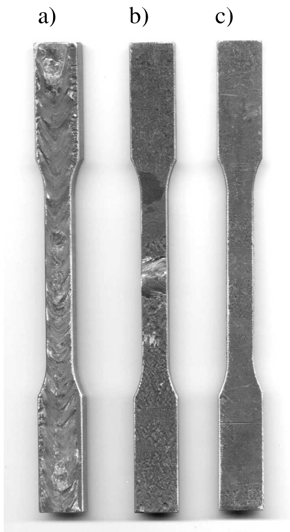

Fig. 2. Tensile specimens – with longitudinal weld (a), transverse weld (b) and base material (c)

For many years strain hardening laws such as those from Ludwig, Hollomon, Voce, Swift and Krupkowski have been used to describe the plastic behaviour of polycrystalline metals and alloys. The Hollomon law in the form of:

$$\sigma = C\varepsilon^{n} \tag{1}$$

has been used the most frequently. The parameters involved in this law, particularly n-value have been correlated to changes in the microstructure of a material and in some way represent processes, which occur during deformation. They have also been used extensively to characterise the formability of sheet material. The value of strain hardening exponent, n, is usually determined from the double logarithmic plot of the true stress and true strain by linear regression.

A of bending experiments have been used to reveal bending characteristics of sheet metals. Most of such tests use two-dimensional geometry for simplified analysis and the simulation, while also being a representative of many industrial parts. In the case of our experimental investigation three rolls bending test was used (Fig. 3). The set-up mounted on the testing machine, instrumentation and process control system allows the rig to operate in displacement as well as load control. As in tensile testing three types of specimens 25 mm wide were deformed:

- continuously to determine bending force characteristic,
- progressively to determine springback characteristic – loaded and unloaded by suitable punch motion – up to nearly 70 mm deflection.

The specimen shape at corresponding bending stage was recorded using the digital photo-camera and stored as .jpg files. Using professional computer code GIMP, the .jpg files were elaborated in order to determine changes in a specimen shape, caused by springback phenomenon, and then the springback coefficient was calculated as:

$$K = \frac{R_a}{R_s} \qquad (2)$$

where: R_a – radius in active phase of bending (under pressure),
R_s – radius in passive phase of bending (after springback).

Fig. 3. Scheme of the three rolls bending test

3. Results and discussion

The results of uniaxial tensile of the 18G2A-E355 steel strips (Table 1 and Fig. 4) demonstrate the visible effect of weld presence in the tested specimen. In comparison with base material characteristic, in the case of welded material characteristic it could be noticed that:

- the presence of weld reduces the value of both the uniform and total elongation, especially in the case of the specimen with transverse weld,
- the value of ultimate strength of specimen with longitudinal weld are higher while that of the specimen with transverse weld are smaller,
- the presence of weld resulted in smaller value of the strain hardening exponent.

Table 1. Mechanical properties of the 18G2A-E355 steel specimens

Specimen type	R_e [MPa]	R_m [MPa]	A_{50} [%]	C [MPa]	n
Base material	308	510	21	593	0.19
Longitudinal weld	354	544	19	637	0.15
Transverse weld	321	480	16	558	0.14

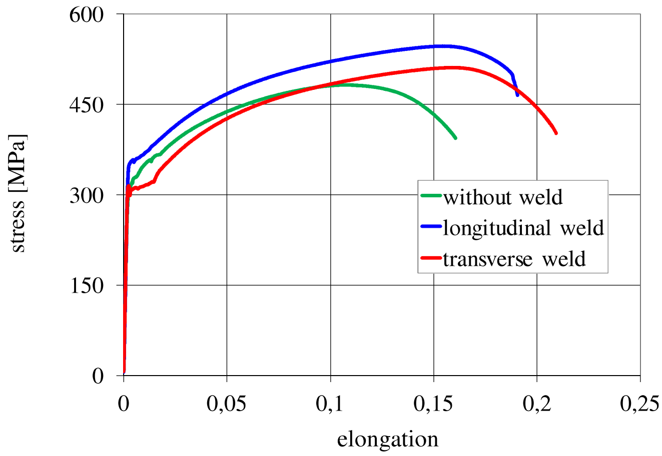

Fig. 4. Flow characteristics of the 18G2A-E355 steel specimens

The highest value of the yield stress and ultimate strength in the case of longitudinal weld resulted from the presence of hard material zone in the centre of weld along the whole specimen in loading direction. The lowest value of the ultimate strength as well as ultimate strain resulted from the presence of two weak material zones located near the weld and oriented transverse to specimen loading. It was confirmed by the strain localisation and specimen failure closed to the weld region.

The bending characteristics, i.e. the relation between bending force and curvature, demonstrate similar run, both in the case of the base material specimen and specimen with longitudinal or transverse weld (Fig. 5). At the first elastic stage of bending, the bending force increases linearly with curvature increase. At the elastic-plastic range of bending the bending force still increases with bending curvature due to strain hardening of a material, and reaches its maximum. At the next stage the bending force started to decrease, as a result of cross-section reduction. The presence of the weld resulted in bending force increasing in the whole range of curvature. This effect is more visible in the case of specimen with longitudinal weld. For the strip with transverse weld the intensity of bending force decrease at the last stage of bending was the most visible.

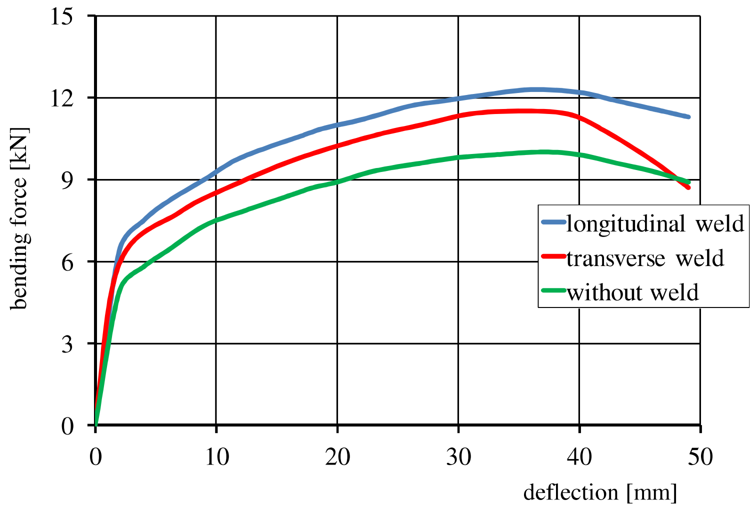

Fig. 5. Bending force characteristics of the 18G2A-E355 steel specimens

The results of springback coefficient calculation were plotted as a function of bending radius (under loading), it means as springback characteristic (Fig. 6). From this presentation it is visible that the value of springback coefficient increases with bending process proceeding, what is a result of elastic zone decreasing in the centre of sheet thickness. The visible change in the springback charecteristic position in comparison with the base material specimen was observed in the case of specimen with longitudinal weld. The presence of transverse weld resulted in slightly larger springback phenomennon, it means smaller value of springback coefficient.

The visible change in springback characteristic in the case of the specimens with longitudinal weld in comparison with that of based material resulted mainly from the presence of hard material zone in the centre of weld located along whole specimen length and oriented along the bending curvature. In the case of the transverse weld, lower values of the springback coefficient in comparison with that of the based material are observed. It seemed to be the result of transverse orientation of the weld (with one hard and two weak material zones) according to the bending curvature and the location of the weld in the region of the bending punch nose.

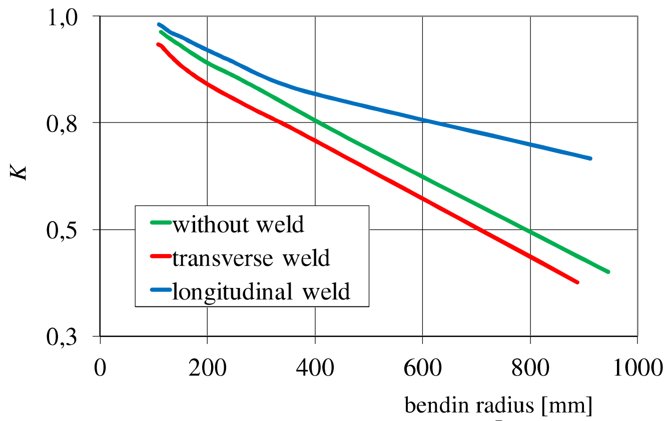

Fig. 6. Springback characteristic of the 18G2A-E355 steel specimens

4. Conclusion

As it should be expected the presence of welding zone in the tested material has the visible effect on both the tensile flow and bending characteristics. The presence of the weld resulted in the bending force increase in the whole range of curvature especially in the case of the specimen with longitudinal weld. Taking into account the springback phenomenon in the case of longitudinal weld this effect could be treated as positive, mainly due to higher value of the springback coefficient in the whole range of bending radius. The presence of transverse weld resulted in decrease of flow characteristic as well as the springback phenomenon is more visible in comparison with the base material (the specimen without any weld).

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SIŁA GIĘCIA ORAZ SPRĘŻYNOWANIE W PROCESIE GIĘCIA SPAWANYCH PASM ZE STALI 18G2A-E355

S t r e s z c z e n i e

W wielu opracowaniach można znaleźć znaczną liczbę informacji dotyczących możliwości gięcia, rodzaju uszkodzeń oraz sprężynowania w procesie gięcia blach jednorodnych oraz łączonych przez spawanie. Jednakże dokładne określenie wielkości powrotnych odkształceń sprężystych nadal wymaga dalszych badań, szczególnie w przypadku gięcia blach grubych. Celem prezentowanych badań eksperymentalnych było określenie siły oraz współczynnika sprężynowania podczas gięcia spawanych pasm ze stali 18G2A-E355. W szczególności skoncentrowano się na porównaniu różnic właściwości mechanicznych oraz charakterystyk gięcia blach jednorodnych oraz spawanych uzyskanych w takich samych warunkach testów. Przyrząd do gięcia zamontowany na maszynie wytrzymałościowej, czujniki oraz system pomiarowy umożliwiały rejestrację przemieszczenia oraz siły gięcia. Spawanie pasm blach przeprowadzono metodą MAG w atmosferze CO_2.

Słowa kluczowe: blachy łączone – spawane, umocnienie odkształceniowe, siła gięcia, sprężynowanie

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