Investigation of Roll Bonding between AA5083 Strips

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ARTICLE INFO

Article history:

Received 5 May 2015
Accepted 2 October 2016
Available online 25 September 2016

Keywords:

Roll bonding
Solid welding
Bond strength
Peel testing

ABSTRACT

Layered alloys and composite materials have become an increasingly popular in industrial development. The roll bonding (RB) process, as a solid phase method of bonding, has been widely used in manufacturing large layered strips. In this study, aluminum alloy (AA 5083) strips were roll bonded at warm and cold temperatures. The effects of the rolling parameters such as the amount of plastic deformation by rolling and rolling temperature that create successful bonds on the bond strength and the threshold deformation between two layer strips of AA 5083/ AA 5083 were investigated. The bond strength was evaluated by the peeling test. It was found that by increasing the rolling temperature or thickness reduction, the peel strengths of the bonds increased and successful bonds with higher strength were created. Also, the threshold thickness reduction decreased with increasing the rolling temperature. Moreover, the interfaces of laminates were studied by scanning electron microscopy (SEM) in order to investigate the bonding quality.

1. Introduction

Aluminum metal matrix composites (Al MMCs) are being considered as a group of new advanced materials in industries due to their light weight, good wear, corrosion resistance, high strength, high modulus of elasticity, and low coefficient of thermal expansion. Due to its unique service performance features, the roll bonding (RB) process has also exhibited a rapid growth and development in recent years among composite material technologies for the production of strips [1, 2].

RB is a solid phase welding process in which the bonding is established by joint plastic deformation of the metals to be bonded. Bonding is obtained when the surface expansion breaks the oxide layers and the roll pressure bonds the surfaces together causing the extrusion of material through any cracks of the fractured oxides that may be present [3].It has been reported that RB of metals is affected by various parameters such as the bonding temperature [4], reduction in thickness of rolling [4], annealing after the RB process [5], the rolling speed [6], the metal under investigation [7], the welding time [8], metal purity [7], lattice structure [7], the surface preparation [9], and geometry of the deformation zone. In order to produce a satisfactory metallurgical bond in the roll bonding process, it is essential to remove the contamination layers between the strips [10]. These layers are composed of absorbed ions (ions of sulphur, phosphor and oxygen), oxides, humidity, dust particles, and grease. Chemical and mechanical treatments are used to remove the contamination layers from the surfaces of the two strips [11].

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There are several investigations regarding the effect of ARB processing on the mechanical and microstructural evolution of aluminum alloys [2, 4]. Specifically, some researchers investigated the effect of ARB processing on the mechanical properties of AA5083. They showed that by increasing the ARB cycles, the strength and hardness of the composites increased as well [12, 13].

Four theories have been proposed to explain the mechanism of pressure welding among the used techniques for the establishment of atom-to-atom bond between metals, i.e. the film theory [9], energy barrier theory [9], joint recrystallization theory [14] and diffusion bonding theory [15]. The film theory has been the major mechanism in cold roll welding due to low rolling temperatures [9]. According to this theory, during the rolling process, two opposing brittle surface layers break up coherently, the underlying metals are exposed, and the virgin material is extruded under the action of normal rolling pressure through widening cracks on both sides of the strips. However, the virgin metal cannot form a strong bond during the roll bonding process if the amount of deformation is less than threshold thickness reduction.

At deformation amounts higher than threshold thickness reduction, the virgin metals are extruded through cracks and metallic bonds are formed on the freshly created surfaces. The scanning electron microscopy (SEM) study of the fractured welding surface by different researchers has confirmed this mechanism [9].

The roll bonding process is one of the most popular methods in recent years to produce sheet metal composites and laminates.

The sheets of AA5083 have been widely used in industry due to their high strength, low density, and high corrosion resistance. Also, as mentioned before, among aluminum alloys, AA5083 has one of the highest values of strength. So, in this study, the weldability of this alloy under the R B process has been investigated for the first time. The aim of the present study is to evaluate the effect of the rolling process parameters that create bonds between two layers of aluminum alloy 5083, the strength of which is comparable to the strength of the original metal. The independent parameters of the RB process are thickness reduction and rolling temperature. Finally, the energy needed for a successful and strong bond in the roll-bonding process was considered. It was concluded that the bond strength approached that of the base metal when the sufficient activation energy to initiate the bonding process was given to the components to be joined. Heating and/or mechanical means may provide this amount of energy.

2. Materials and methods

The ARB technique is used to fabricate metal matrix composites. The one cycle ARBed samples or RBed samples were sheets of annealed commercial aluminum alloy AA5083 strips with the initial dimensions of 100 × 30 × 1 mm which were annealed at 400°C for 1 hour to ensure consistent specimen hardness. In the present study, the commercial aluminum alloy namely AA5083 was used for RB processing. The detailed chemical compositions and mechanical properties of aluminum alloy 5083 are given in Tables 1 and 2, respectively.

Table 1. Chemical composition of AA5083.

Element	Al	Cr	Si	Fe	Mn	Zn	Ti	Cu	Mg
Wt%	balance	0.21	0.23	0.18	0.51	0.23	0.003	0.08	4.5

Table 2. Mechanical properties of AA5083.

Grade	Temper	Tensile strength (Mpa)	Yield strength (Mpa)	Elongation,%	Hardness, HV
AA5083	o	290	145	29	26.3

To produce a satisfactory metallurgical bond by RB, it is essential to remove contaminants from the surfaces of the strips to be joined. These layers are composed of greases, oxides, adsorbed ions, and dust particles. So, AA5083 strips were degreased in acetone bath and scratch brushed with a 90 mm diameter stainless steel circumferential brush with 0.35 mm wire diameter at a speed of 2500 rpm in order to remove the oxide layer on the surfaces of strips, as can be seen in Fig.1. In order to remove the oxide layer from the surfaces of strips, two strips of AA5083 were stacked together to achieve 2 mm thickness. Proper alignment of the two strip surfaces prior to rolling is necessary. Then, the stacked strips were fastened by steel wires at both ends and were roll bonded with different thickness reductions at various rolling temperatures from 25°C up to 400°C. The experiments were set up based on the effect of roll bonding conditions such as the rolling temperature (25, 100, 150, 200, 250 and 300°C) and the ratio of thickness reduction (20, 30, 40, 50, 60 and 70 pct.) on the peeling force and the peeling surface of the samples. For each experiment, three samples were prepared.

The roll welding experiments were carried out using a laboratory rolling mill with 170 mm roll diameter, 36 rpm of rotational speed, and a power capacity of 35hp.

After surface preparation, the handling of strips was carefully performed to avoid renewed contamination. The time between surface preparation and rolling was kept to less than 120 s to avoid the formation of a thick and continuous oxide layer on the bond surfaces of the strips. Then, the two metal strips to be joined were positioned with the two prepared intimate surfaces against each other. For this metal combination, a series of rolling experiments were carried out using the rolling reductions between 10% and 70%. In order to study the effect of temperature on the bond strength between layers, the rolling was carried out at temperatures between 25 and 400 °C. The bond strength of the samples was measured using a peeling test according to ASTM-D903-93 standard and for each sample, the tensile test was repeated three times. In the peeling test, the average peeling forces were measured, as shown typically in Fig. 2 and the average peel strength was taken as shown in Fig. 3.

$$\text{Average peel strength} = \frac{\text{Average load}}{\text{Bond width}}$$

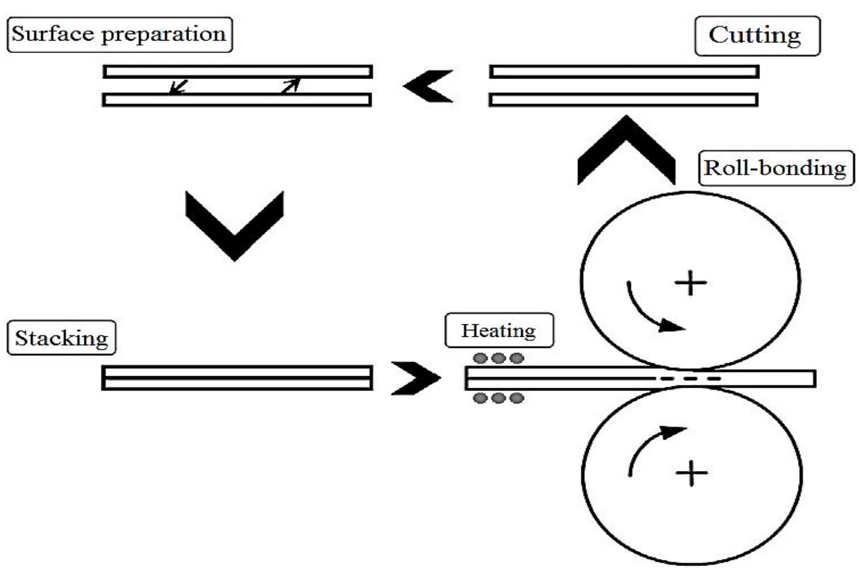

Fig.1. Schematic diagram of the roll bonding (RB) process.

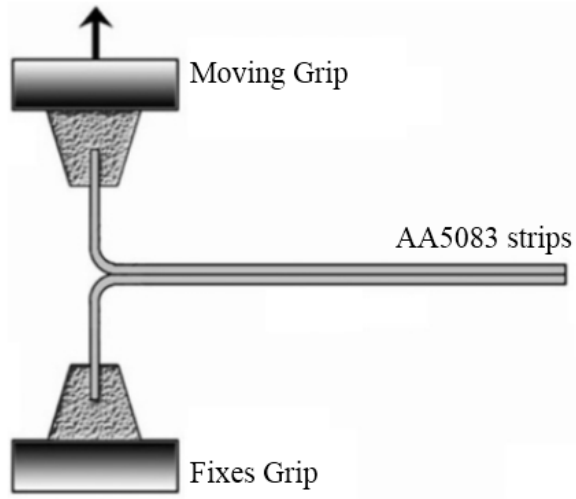

Fig. 2. Schematic illustration of the peeling test fixture.

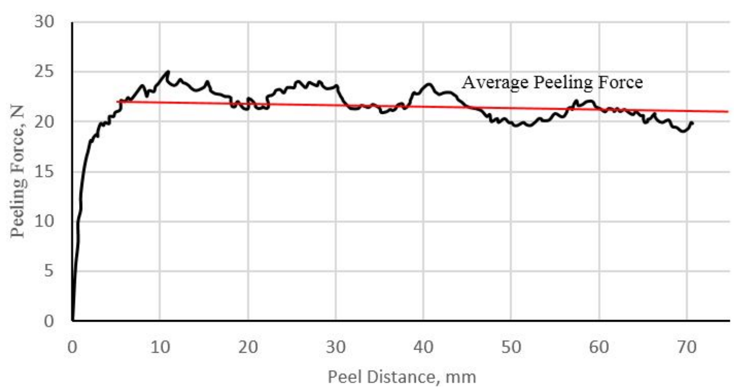

Fig. 3. Typical plot of the peeling force versus the peel distance.

3. Results and discussion

3.1. Effect of thickness reduction on the bond strength

Fig. 4 shows the effect of total thickness reduction of rolling on the bond strength of two-layer strips of AA5083 at ambient temperature. As can be seen in Fig. 4, the threshold thickness reduction during the rolling process for producing the bond between AA5083 strips is about 27%. Also, the bond strength increases rapidly with deformation, reaching a plateau corresponding to the strength of the base metal [9]. Among the many parameters affecting weld formation, deformation is the most important parameters in cold welding processes such as rolling [3]. According to Fig. 4, bonding does not occur until a threshold deformation is reached [10, 11], which is about 27% for AA5083/AA5083 strips. Moreover, by increasing the total thickness reduction with regard to threshold deformation the bond strength increases rapidly [9] which is due to the increase of contact mean pressure and the overlapping surface exposure at the interface of strips [10].

According to Fig. 5, metallic bonding occurs between freshly created surfaces [9]. As mentioned before, under total deformation less than threshold deformation, less cracks and consequently negligible virgin metal surfaces were created and therefore no bonding between the layers occurred [11].

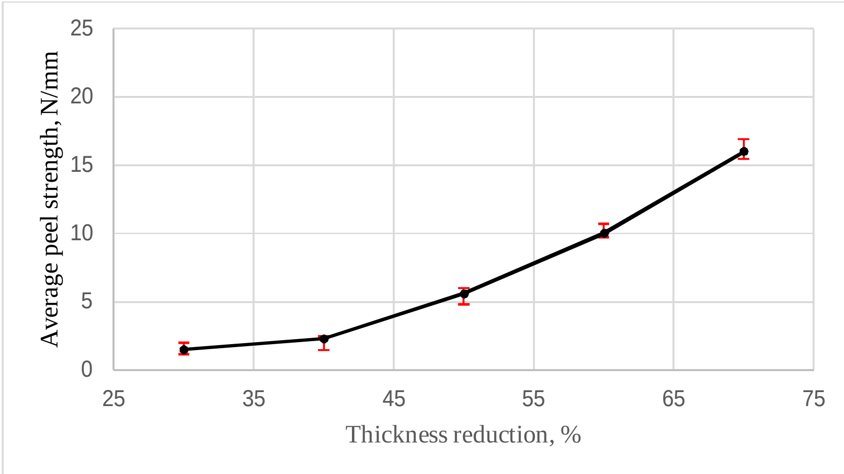

Fig. 4. Variation of the average peel strength of two-layer strips of Al/Al versus total thickness reduction.

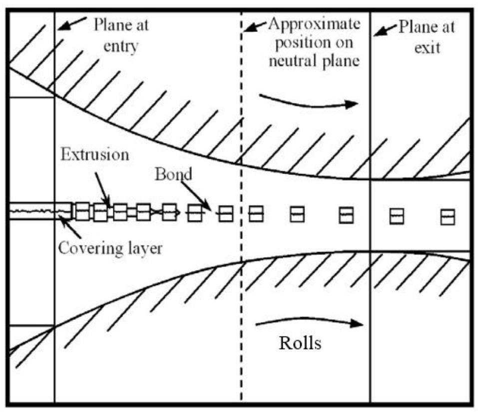

Fig. 5. Schematic illustration of the bonding mechanism in the rolling length of contact [5].

However, by increasing the thickness reduction, the number of cracks increases and as a result, more virgin metal surfaces were exposed in contact surfaces. Then, the area available for atom-to-atom bond was extended and the bond strength between layers increased [11].

Fig. 6 shows the schematic illustration of the bonding mechanism. As can be seen in this figure, no bonds are visible as the extrusion of virgin material through the cracks at the outset of entry plane is initiated. Then, by increasing the amount of surface expansion, contact is established between the highest asperities of the virgin material of the two opposing surfaces to form a metallic bond. With a considerably larger surface expansion, the extensive areas of the metal are uncovered and numerous bonds are formed. The un-bonded regions of the brittle surface layer at the interface are confined to small isolated islands [5]. It is useful to investigate the interface in bimetallic strips. The interface of the samples were studied by SEM.

Fig. 7 shows the features of the interface between the component layers. Figs. 7(a, b) show the interfaces between the AA5083 layers after the roll bonding process with 10% and 70% ratios at 200°C. According to Fig. 7(a), after the roll bonding with a low thickness reduction (i.e. 10 pct.), there are some residual voids at the interface. By increasing the roll bonding reduction up to 70pct, the interface bond quality is significantly improved, so it is very difficult to identify the interface between the layers in the micrograph (Fig. 7(b)).

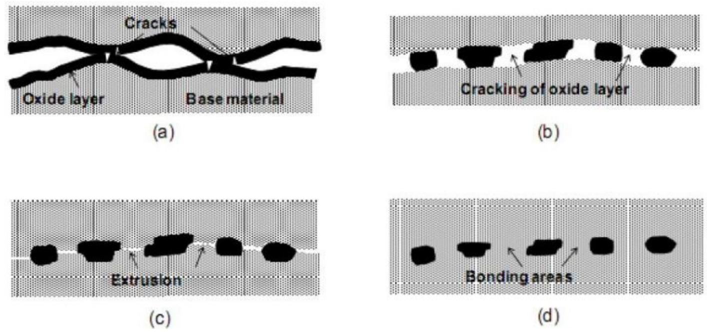

Fig. 6. The progression of bonding between two aluminum layers under increasing load [2].

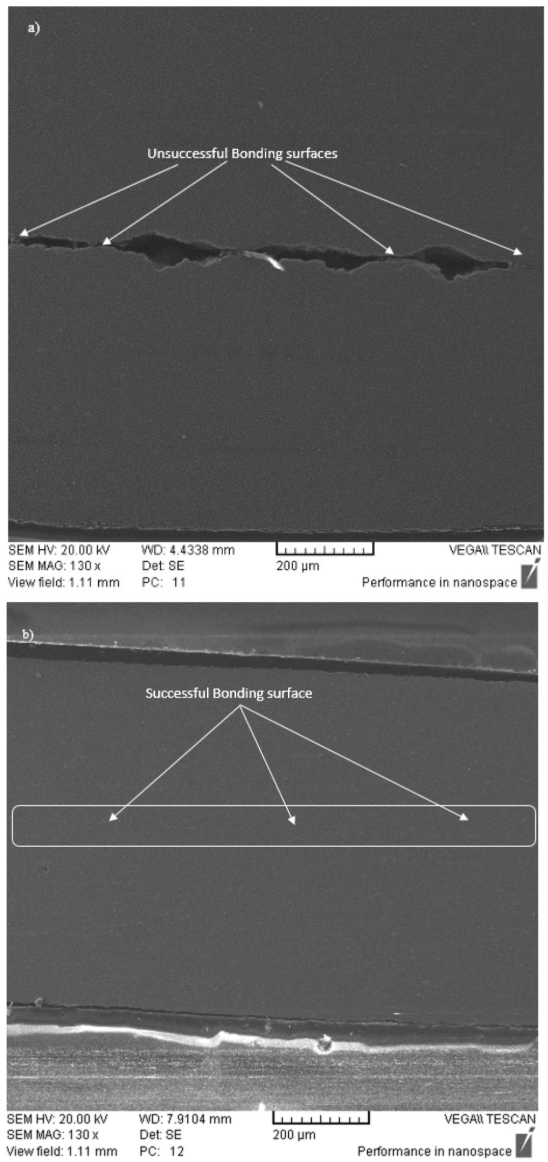

Fig. 7. SEM images of cross section of the samples:
(a) With 10 and (b) with 70 pct. of thickness reduction at 200°C.

According to Fig. 7, no bonds are visible at the start ofthe extrusion of virgin material through the cracks at the outset of entry plane. Then, by increasing the amount of surface expansion, contact is established between the highest asperities of the virgin material of the two opposing surfaces to form a metallic bond.

With a considerably larger surface expansion, the extensive areas of the base metal are uncovered and numerous bonds are formed. So, the unbonded regions of the brittle surface layer at the interface are confined to small isolated islands [5].

3.2. Effect of the rolling temperature on the bond strength and threshold deformation

Fig. 8 shows the effect of total thickness reduction of rolling on the bond strength of two-layer strips of AA5083 at ambient temperature. As can be seen in Fig. 8, the threshold thickness reduction during the rolling process for producing the bond between AA5083 strips is about 27%. Also, the bond strength increases rapidly with deformation, reaching a plateau corresponding to the strength of the base metal [9]. Among the many parameters affecting weld formation, deformation is the most important parameter in cold welding processes such as rolling [3].

As mentioned before, bonding does not occur until a threshold deformation is reached [9], which is about 27% for AA5083/AA5083 strips. Moreover, by increasing the total thickness reduction with regard to threshold deformation the bond strength increases rapidly [11], which is due to the increasing of contact mean pressure and the overlapping surface exposure at the interface of strips [10].

Under total deformation less than threshold deformation, less cracks and consequently negligible virgin metal surfaces are created and therefore no bonding between the layers occurs [10].

However, by increasing the thickness reduction, the number of cracks increases and, as a result, more virgin metal surfaces flow in contact surfaces. Then, the area available for atom-to-atom bond is extended and the bond strength between layers is improved [9].

3.3. Effect of the rolling temperature on the bond strength and the threshold deformation

Figs. 8, 9, and 10 show the variation of the bond strength versus the rolling temperature at constant total thickness reduction. By decreasing the flow stress of metals at higher rolling temperatures, the bond strength at the interface increases [9]. Thus, at higher rolling temperatures, the ductility and formability of virgin metals in underlying surfaces are increased and their extrusion through more cracks in contact surfaces is enhanced, in comparison to low temperatures. As a result, the ratio between the bond area and the area available for bonding increases and the bond strength between layers is improved with increasing the rolling temperature [14].

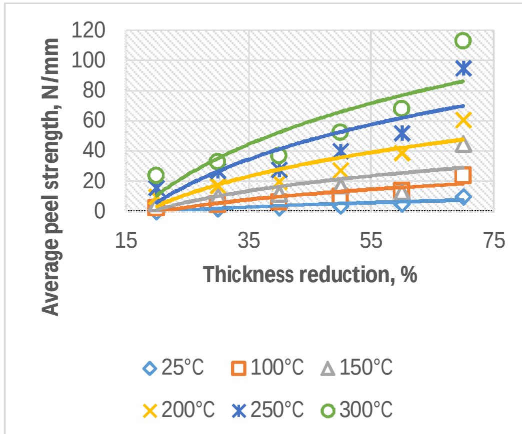

Fig. 8. Variation of the average peel strength of two-layer strips of Al/Al versus total thickness reduction at different rolling temperatures (Log-experimental).

Threshold deformation for the accomplishment of bonding decreases with rolling temperature, as shown in Fig. 10. Roll bonding is justified by energy barrier theory, too [19]. It has been suggested that an energy barrier must be surmounted before two virgin metal surfaces can meet and bond together [16]. In the case of solid welding of the roll bonding process, the existence of a threshold deformation has lent support to the energy barrier hypothesis [9]. So, during the roll bonding process, in contact surfaces, the required energy for rearrangement the boundary configuration of surface atoms [9], the dispersal of surface contaminants [20], and activation energy for atom to atom bond formation [20] constitute an energy barrier. Thus, the energy needed to overcome an energy barrier is supported by increasing of rolling temperature, removing the surface contaminants by surface preparation and pressure implementation during deformation.

In the roll bonding process at higher rolling temperatures, on the other hand, higher thermal energy exists to overcome the energy barrier, and consequently the deformation required for bonding decreases.

So, increasing of the rolling temperature leads to less threshold thickness reduction required for the establishment of the bond in contact surfaces.

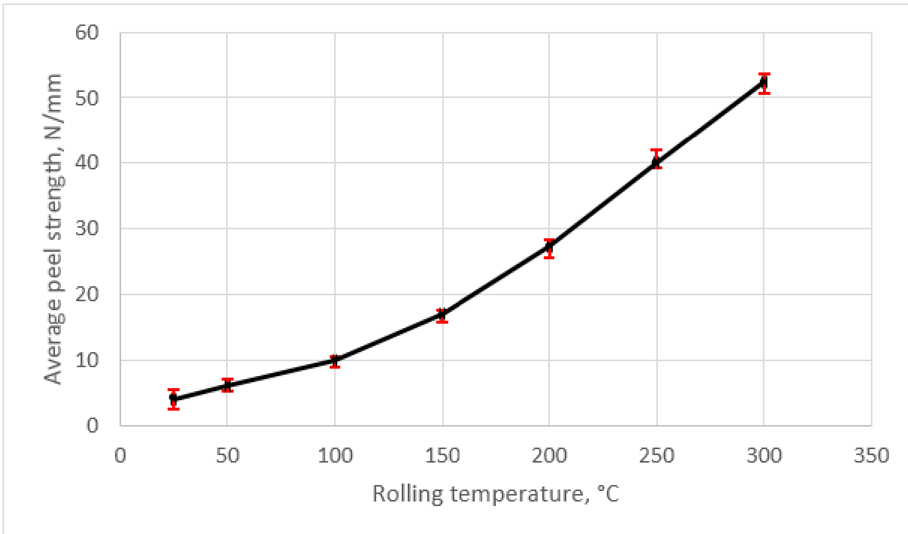

Fig. 9. Variation of the average peel strength of two-layer strips of Al/Al versus the rolling temperature.

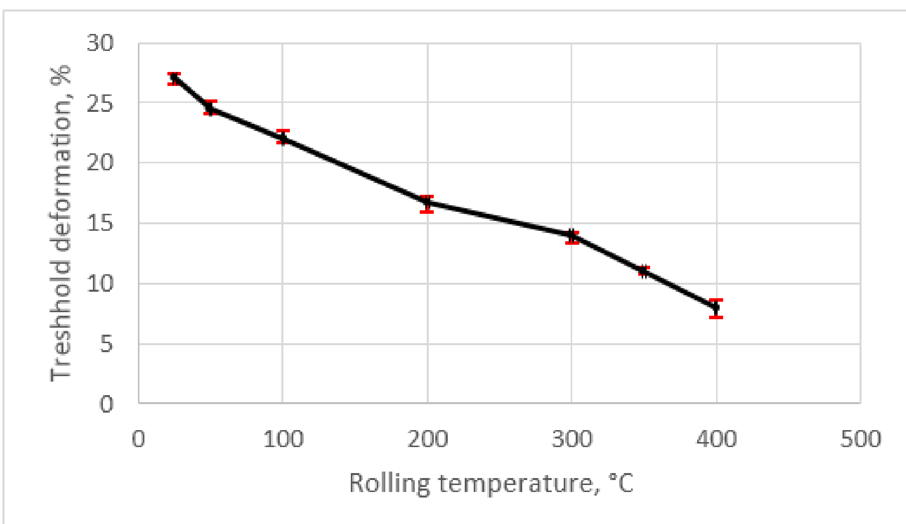

Fig. 10. Variation of threshold deformation in aluminum-1100 strips versus the rolling temperature.

4. Conclusions

The bond strength between the two layer AA5083/AA5083 strips produced by the roll bonding process at different thickness reductions and rolling temperatures was attained and measured by peeling test. The following conclusions can be highlighted briefly:

1. The threshold deformation for roll bonding of AA5083 to AA5083 is about 27% total thickness reduction at ambient temperature.
2. The bond strength of AA5083/ AA5083strips increased with increasing the total thickness reduction until the bond strength reaches the plateau corresponding to the strength of AA5083. Increasing the amount of plastic deformation leads to increasing the number of cracks, fissures, and therefore, the total cracks area.
3. Increasing the temperature in the roll bonding process decreases the amount of threshold thickness reduction needed for a successful bonding between layers.
4. Increasing the rolling temperature at constant total thickness leads to the increase of the bond strength of two layered AA5083/ AA5083 strips.

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