Sustainability aspects in the warm forming of tailor welded blanks

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Abstract. Tailor welded blank (TWB) technology has been used in the manufacture of automobile body-in-white components since a long time. These components consist of different materials/thicknesses. Researchers and manufacturers involved with production of warm formed TWB components failed to address the sustainable issues related to warm forming. Rather they concentrated more on reducing the weld line movement (WLM). The WLM if not arrested shall lead to fracture, due to wrinkles, produced during forming. In this paper, the sustainability aspects involved in the warm forming of TWB were discussed with respect to energy and material savings. The results show a reduction of about 50% punch load in a hydraulic press during deep drawing under warm forming conditions. This paper addresses the questions related to the implications of thickness ratio on the weld line movement and further shows how material savings of nearly 33% has been obtained. It also discusses about the carbon emissions during manufacturing of raw materials and the recycling benefits of stainless steel, so as to minimize emissions at the production stage itself during raw materials production.

1 Introduction

Automobile manufacturers worldwide are focusing on designing and manufacturing light weight Body-in-White (BIW) components due to the growing concern expressed by various governments to control environmental pollution caused by the vehicle emissions. It is a known fact that, the fuel efficiency is directly proportional to the weight of the vehicle. In this context, the tailor welded blank technology (TWB) has come into existence about two decades ago[1] to manufacture light weight automotive body parts. Sustainable production of TWBs in the manufacture of BIW components is growing at a rapid pace, with nearly 30% components being manufactured by TWB technology alone. In addition to this, the use of scrap sheet metal as well, and to meet certain geometry requirements and functional strength, the sustainability of using tailor welded blank (TWB) process is adopted in automobile industry [2].

Sustainable manufacturing issues related to sheet metal forming processes are widely investigated. Ingarao et al. [3] investigated sustainability aspects in sheet metal forming processes. They focused on the efficient use of energy and material savings in stamping process based on the initial blank design. They concluded that different methodologies need to be applied for energy and material savings and both cannot be clubbed. Cooper et al. [4] studied the traditional and latest methods of sheet forming based on the electrical power requirements in the die design. Their results showed that idling consumed more electricity. They found that there are significant potential savings for small production runs, consistent with part development/prototyping. However, these savings varied depending on the part size. The results of their study highlighted that for small production numbers over the die lifespan, the impacts of die-making are important. However, as production numbers increase above one hundred parts per die-set, the impacts of making the sheet metal become dominant. It is therefore concluded that researchers interested in reducing the environmental impacts of sheet metal forming concentrate on innovations that would reduce sheet metal blanking and post-forming trimming losses. Campana et al. [5] demonstrated how the weight reduction affected the CO_2 emissions. They used topology optimization method to produce light weight components, thereby resource-saving. Pereira and Rolfe [6] studied the frictional heating aspects occurring during stamping operation which are responsible for high die temperature. They have carried out both simulations involving thermo-mechanical FE model and experiments. They concluded that the process speed and blank material strength strongly influence maximum temperatures. The results showed direct influence of temperature on tool wear performance during stamping operation. Hon [7] discussed that the maximum force measured on a TWB does not lie halfway between the maximum forces of both materials, but that the higher strength steel contributes 40% and the lower material contributes 60% of the maximum force of the TWB. He explained that since the hard material displaces the soft material and consequently, the hard material requires less force for being formed. Mayyas et al. [8] discussed on the use of stronger materials which have a high and

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sustained work hardening effect for producing light weight structures. It allows the automobile manufacturers to use thinner materials resulting in less weight. They also suggested using TWB to custom make the thickness of blanks according to their location performance criteria. Krause and Seliger [9] studied the influence of weld position on the environmental aspects during the forming of TWB. They studied the simple life cycle energy model and concluded that it is better to reduce the product weight rather than reducing the waste weight.

1.1 Impact of producing raw materials on the environment

The vehicle's entire life cycle should be considered for setting targets on vehicle emission, and not the emissions alone. Since steel has higher density (which leads to overweight), automobile makers will be tempted to use lighter materials such as aluminum and Magnesium to replace steel. Though, lighter materials release lesser emissions during movement, however, the production of lighter materials releases more carbon into the atmosphere during production in comparison with steel manufacture.

A 25% vehicle weight reduction results in about 20% reduction in fuel consumption [10]. Production of lighter materials used in vehicle manufacture viz. carbon fiber reinforced plastic (CFRP), magnesium and aluminum generate high levels of green house gas emissions compared to production of steel as shown in the Figure 1. Thus, a complete life cycle assessment is required towards the sustainability of resources especially on vehicle emissions

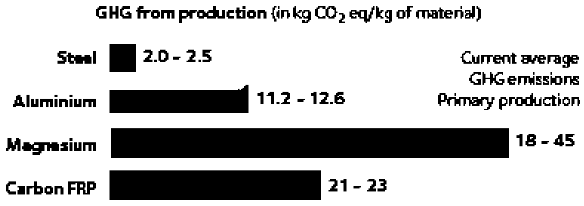


Fig. 1. Green house gas emissions from the production of materials (Source: World Auto Steel)

1.2 Recyclability of materials

Majority of the lighter materials cannot be recycled cent percent, unlike steel which can be recycled fully. Thus, steels have the potential to reduce green house gases. Even aluminum recycle rate is between 60% and 70% only, whereas about 96% of steel can be recovered and recycled. According to world steel body, every tonne of recycled steel saves an average of 1.5 tonnes of GHG emissions. With all the above mentioned advantages, automobile manufacturers started using more steel in their BIW components.

In this paper, the sustainable aspects involved in the warm forming of TWBs has been with respect to energy and material savings in the manufacturing of TWB components.

2. Preparation of TWB samples

Based on the volume constancy, the standard equation for obtaining the diameter of the circular blank, is collected from the literature [11] for drawing a successful cup.

$$D = \sqrt{d^2 + 4dh} \tag{1}$$

Here D = blank diameter, d = cup diameter and h = height of the cylindrical cup without considering the punch corner radius. TWB samples were prepared from Austenitic stainless steel of grade ASS 304 and mild steel of grade IS 513 materials. Semi-circular blanks with diameter 75 mm were cut from the respective steel materials which are later fusion welded using TIG welding process with the welding parameters as listed in Table 1. The weld bead measured with the help of a vernier caliper gave a result of 3 mm width.

Table 1. TIG welding parameters

Parameter	Value
Welding current	80-100 Amps
Welding speed	3.2 mm/s
Heat input	2.18 kJ/min
Rated output voltage	25 V
Shielding gas	Argon
Gas flow	12 L/min

The two sheet materials which formed a TWB blank was subjected to deep drawing operation on a hydraulic press. A split punch is fitted in the hydraulic press to selectively heat the TWB blank. A schematic diagram representing the split punch is shown in Figure 2 [12,13].

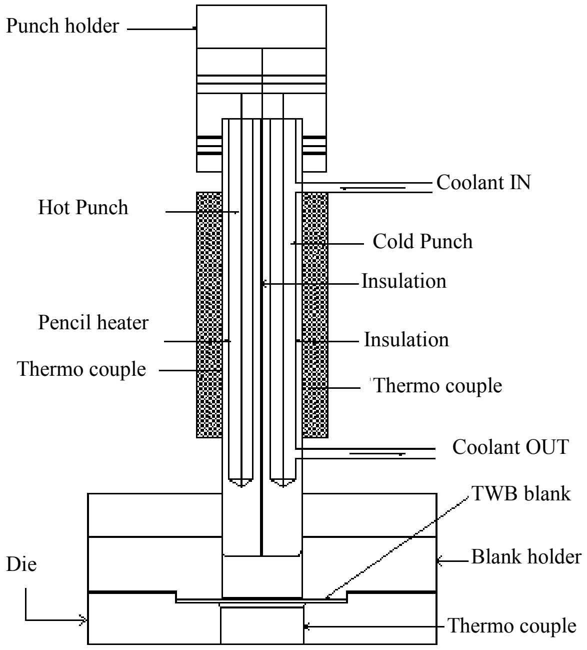


Fig. 2. Schematic diagram of die setup with split punch

The split punch has a provision to insert a pencil heater in one part of the punch to heat the stronger material among the TWB, while the other part is allowed to circulate ice cooled water from outside arrangement. The heated part of the punch was allowed to be in contact with the high strength material i.e. in this case ASS 304, and the other side of punch was in contact with the low strength material, viz. IS 513 material during forming. In order to reduce heat dissipation into the environment, cotton wool insulation is provided around the punch. To measure the temperature of punch and the respective blanks, thermocouples were placed at selected locations. During the process, the punch travel was allowed to maintain a uniform velocity of 400 mm/min. In order to prevent the formation of wrinkles, a 10 kN uniform blank holder force was applied on the blank.

Laboratory experiments were conducted in obtaining a reasonable limiting drawing ratio (L/D ratio) until no fractures were noticed in the cups. TWB cups were deep drawn at room temperature as well as at elevated temperatures of 100° C and 150° C to produce 46 mm cup diameter. Load displacement graph obtained during forming of TWB cup at different temperatures is shown in Figure 3. The punch travel was limited about 20 mm.

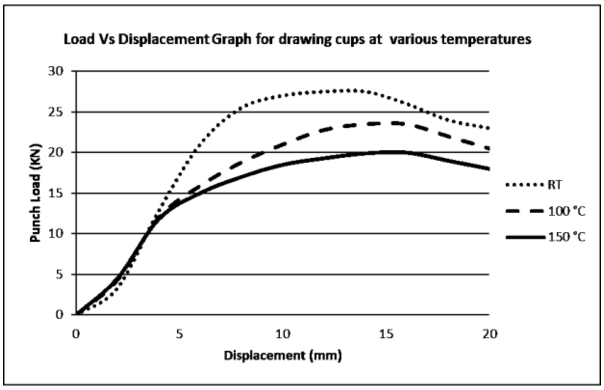


Fig. 3. Load displacement graph of TWB cups drawn at different temperatures

3. Results and Discussion

3.1 Energy savings in heat assisted forming process

The power consumption during forming can be calculated as [14]:

Energy consumed = Load * displacement

Comparisons were made with respect to the power consumed in forming of TWB component at different temperatures. The area under the curve is considered in determining the energy consumption during the deep drawing operation carried out on the hydraulic press. The initial peaks are due to the limiting friction between the punch and the sheet material. It can be observed that the energy required to overcome limiting friction is more in case of cups formed with heating as compared to the cups formed without heat before drawing operation. In order to avoid the friction aspects, it is suggested to provide lubrication just before drawing operation is carried out, otherwise heat causes changes in friction. However, the total energy consumed for the products formed at room temperature is more than that of the products which are formed using the heat assisted forming method as shown in Table 2.

Table 2. Energy consumed by hydraulic press while drawing TWB cups at different temperatures

Temperature	RT (30° C)	100° C	150° C
Energy consumed	450.5 J	335 J	292 J

Comparing the energies consumed by the hydraulic press while drawing the TWB cups at room temperature as well as elevated temperatures, it is estimated that nearly 34% energy has been saved when the cups were heated at 100° C and about 54% energy has been saved by heating at 150° C. So, reduced investment is needed in procuring hydraulic press, since it needs lesser capacity.

The total energy calculated on hourly basis (which includes friction energy, heat energy, punch load etc.) to form a TWB component using heat assisted forming is less than the energy required to form at room temperature as shown in the Figure 4.

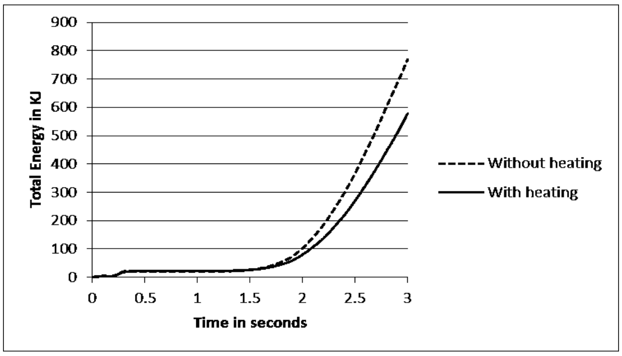


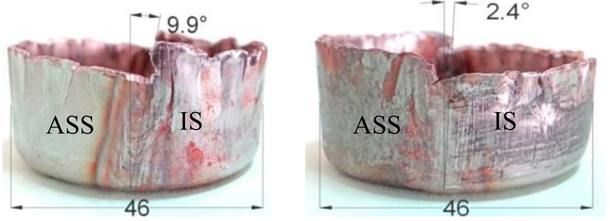
Fig. 4. shows the comparison with respect to the total energy consumed in the stamping of TWB cup at both temperatures

3.2 Material savings in heat assisted forming of TWBs

The main purpose of using TWB components in automobiles is to reduce the weight of BIW components. That doesn't mean that the components shall be compromised with structural rigidity and crashworthiness. While maintaining all parameters, weight reduction is undertaken. During forming of TWBs, WLM give rise to wrinkling due to variations in thicknesses/strengths of the respective sheet materials. In order to restrict the WLM completely, the method of adopting warm forming TWB along with the variations in thickness ratio is an attempt to obtain defect free components.

3.2.1 Weld line movement in a TWB with thickness ratio of 1

Weld line movement was severe in TWBs when formed at room temperature [11]. Deep drawing operation carried out experimentally at room temperature for the sheet thicknesses of 1 mm each resulted in a weld line movement of 9.9° in the deformed cup wall as shown in the figure 5(a). However, it reduced to 2.4° when the TWB blank was subjected to elevated temperature of 150°C for the same thicknesses as shown in Figure 5(b).



(a) (b)

Fig. 5. Weld line movement in the TWB cup formed at (a) Room temperature (b) 150°C.

Weld line appeared to be inclined with respect to the vertical as shown in the Figure 5(a), which suggests that there is a considerable movement of weld line. Experiments conducted at elevated temperature of 150°C resulted in almost a straight weld line as per Figure 5(b).

Simulation measurements gave similar results. Comparison between the simulated and experimental results is shown in Table 3. The deviation in the weld line movement has been measured with respect to cup bottom from its center.

Table 3. Measurements in the TWB cup for thickness ratio of 1

Temperature	Results	WLM (mm)	Cup diameter (mm)	Cup height (mm)
30° C	Experimental	-1.6	45.8	24.9
	Simulation	-2.26	45.6	22.8
150° C	Experimental	-0.2	43.5	21.8
	Simulation	-0.56	44.2	19.6

The movements of weld line measured with respect to the centre of the cup using LS Dyna software, thus substantiated with the experimental results. TWB cup formed at room temperature resulted in a weld line movement of 2.26 mm at the cup bottom. It reduced to 0.56 mm when the cup was formed at elevated temperature of 150° C.

3.2.2 Weld line movement in a TWB for thickness ratio of 1.5

Simulation experiments were conducted for carrying out further stamping operations for thickness ratio of 1.5. The thickness of ASS material chosen was 0.66 mm to achieve a thickness ratio of 1.5, keeping the thickness of IS material constant at 1 mm. After stamping, the weld line moved by about 1.75 mm towards the IS side. Forming at elevated temperature resulted in an increase in the weld line movement to about 4.94 mm on the same side. The direction of weld line movement shifted from one side to the other when thickness ratio increased. It can be realized that the WLM at TR=1 resulted in negative values as shown in Table 3, while the WLM at TR=1.5 resulted in positive values of measurements as shown in Table 4.

Table 4 Simulation results of TWB cup for thickness ratio of 1.5

Temperature	WLM (mm)	Cup diameter (mm)	Cup height (mm)
30° C	+1.75	45.8	21.8
150° C	+4.94	44.9	19.7

3.2.3 Comparison of WLM at different thickness ratio

As the thickness ratio increased, a reduction in the weld line movement was noticed at both room temperature as well as at elevated temperature. Comparisons of WLM in TWBs at different TR were shown in the Figure 6 when stamping operations were conducted at different temperatures. The WLM consisting of negative values indicate that the weld line shifted laterally towards the ASS material side with respect to the centre. As the thickness ratio increased from 1 to 1.5, the shift in WLM was towards the IS material side as observed in the formed cups at room temperature and elevated temperature as well. The WLM at TR= 1 was marginal when the cups were formed at room temperature conditions while it is greater when the cups were formed at elevated temperature. If the thickness ratio is maintained correctly, the movement of weld line can be reduced to a large extent when heat assisted forming is used.

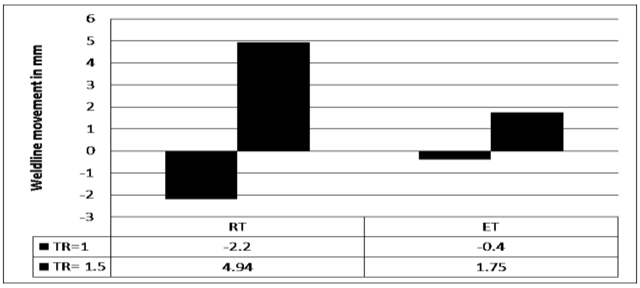


Fig. 6. Bar chart depicting the WLM at TR=1 and 1.5 in the forming of TWBs at different temperatures

3.3 Thinning aspects in the formed TWB cup

In order to carry out sheet formability analysis, it is mandatory to assume the allowable thinning of sheet during forming operation. It was assumed that the essential thinning is 20% and allowable thinning is 30% with allowable thickening of 1% based on the works carried out by Trzepiecinski et al. [15]. Thickness distribution was analyzed from the simulations experiments for thickness ratio of 1 and 1,5. Since it is difficult to measure thickness using conventional tools, graphs obtained from LS-Dyna software were necessary for plotting the thinning behavior of TWB materials. The graphs were used to plot the thinning behavior of ASS material during forming at room temperature as well as at elevated temperature as shown in the Figure 7. The thickness of ASS material reduced to about 0.87 mm at the punch corner from the initial sheet thickness of 1 mm when the TWB was formed at room temperature. Forming at elevated temperature resulted in a thickness of about 0.85 mm in the same material at the same location. The results showed that the thickness of ASS material has reduced by about 0.02 mm more, when the stronger material (ASS) was subjected to heating. It predicts the chance of a fracture in the ASS material when subjected to elevated temperature. It also confirms that the ASS material is softening due to the application of heat, allowing more material to flow into the die, thus resulting in the movement of weld line towards the IS side.

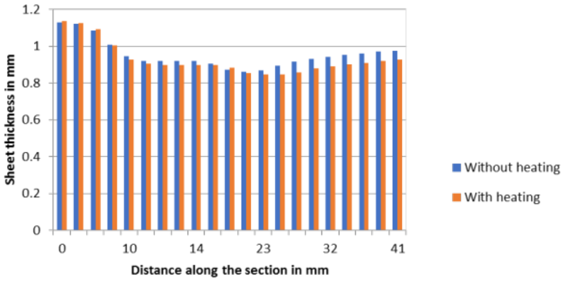


Fig. 7. Bar chart depicting the comparison of thickness distribution in the formed cup for TR=1

When the thickness ratio changed to 1.5 i.e., the thickness of ASS has been varied while maintaining the other sheet thickness (IS) constant. In this case, the effect of thinning distribution in ASS material alone was considered.

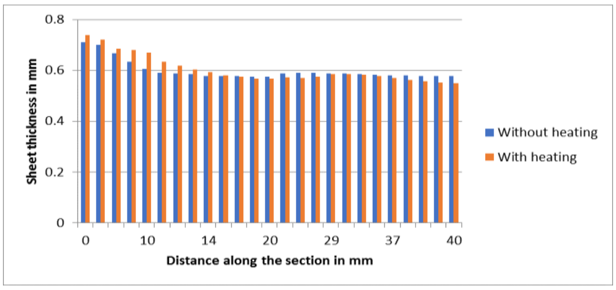


Fig. 8. Bar chart depicting the comparison of thickness distribution in the formed cup for TR=1.5

It has been observed that the thickness of ASS material reduced to about 0.56 mm from the initial thickness of 0.66 mm when the TWB was formed at room temperature and it reduced further to 0.55 mm when formed at elevated temperature as shown in Figure 8. Thus, the margin of decrease in sheet thickness is same at both temperatures under the allowable thinning aspects. Thus, material savings of about 33% has been achieved by changing the thickness ratio.

4. Conclusions

In this paper, the sustainable aspects involved with respect to material and energy savings in the warm forming of TWBs were discussed. According to the process, the warm forming method considerably helped in reducing the weld line movement to a greater extent, especially at higher thickness ratio. The load on the hydraulic press during warm forming resulted in energy savings. By reducing the thickness of the sheets, the weight of the formed component has been brought down, thus contributing to material savings. This process led to overall savings and also improved the accuracy of the products. It showed that the total energy consumption was lower during entire forming operation. The analyses of power consumption and minimum weld line movement have proven that the usage of warm forming process in the manufacture of tailor welded blanks components guarantee the application of this method in automobile industries.

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