Enhancement in mechanical properties of tailored welded blanks due to pulsed tig welding

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ABSTRACT

The present paper reports experimental results on enhancement in mechanical properties of tailored welded blanks due to Pulsed TIG welding. Experimental evaluation of various mechanical properties has been made under the influence of varying peak current, pulse frequency and pulse width. The resulting welds have been checked for ultimate tensile strength, % elongation, hardness, toughness and fatigue life. The mechanical properties of Pulsed TIG welded tailored blanks have further been compared with that produced by conventional TIG welding. It has been observed that the Pulsed TIG welding can successfully be employed to improve the mechanical properties of tailored welded blanks. The results of experiments have been analyzed and related discussion has been presented.

Keywords: Pulsed TIG welding; Mechanical properties; Tailored welded blanks

INTRODUCTION

Welded joints of different sheet thickness or material commonly referred as tailor welded blanks (TWB) have become the most established with the automotive industry [1]. The concept of TWB was originated in mid 1980s. By mid 1990s application of TWB in manufacturing was firstly adopted by the automotive sector [2]. In the later stage, by the beginning of 2000s applications of TWB have also been reported in other sections like building sector [3] and lightweight constructions [4]. TWB are produced as an intermediate semi-product that can further be utilized as per the application. In particular, potential of Aluminium TWB for selectively reinforcing the stiffness of parts and for reducing the vehicle weights can be found in literature [5]. Different welding process like tungsten inert gas (TIG) welding [6], laser welding [7, 8 and 9], mash seam welding [10], MIG welding [11], friction stir welding [12] etc. have been used to produced TWBs. Generally, TWBs are referred to butt-joint of dissimilar thickness or material, however, some researchers also considers other joints like axial joining of two dissimilar thickness or outer diameter tubes [11] as TWB.

With increasing demand for TWB, investigation into TWB has considerably increased. These investigations can be categorized in two directions including application of TWB and production of TWB. The research in the first category has been mainly related with behaviour of TWB during different manufacturing operations like forming, deep drawing, stamping etc. [13-18]. The second category has been related with application of different joining process to produce TWB [19-25] and resulting studies regarding mechanical properties and micro-structural patterns [26-32]. The present investigation is aimed to examine and quantify the effect of Pulsed TIG welding process parameters on mechanical properties of TWB. Thus, the subsequent section describes the past investigation into production of TWB by different joining techniques and resulting outcomes. The same section further indicates the motive behind the present study and gives a small description of Pulsed TIG welding process. The following section covers the experimental work. The resulting effects of process parameters on mechanical properties have been presented and discussed in the subsequent section. The last section draws conclusions arrived at during the present investigation.

PAST INVESTIGATIONS

Investigations into manufacturing of TWB and resulting mechanical properties started to appear in mid 1990s. One of the earlier investigations [26] reported development of welding procedures for CO_2 laser beam welding of Aluminium 5754-O and 6111-T4 alloys for application in tailored welded blanks. This investigation indicated that TWB can be laser welded with full penetration and minimum surface discontinuities. Another investigation [19] with the same process, i.e., CO_2 laser beam welding, dealt with the effects of shielding gases on CO_2 laser on weldability of low carbon automotive galvanized steel. It has been found that weld penetration, strength and formability of welds depend on the type of shielding gas used. Davies et al. [27-28] reported application of TIG welding process and resulting weld metal ductility in Aluminium TWB. Tusek et al. [11] investigated into MIG and laser welded steel TWB and concluded that tailored blanks of high-alloy stainless steel cannot be laser or TIG welded to those of low-alloyed ferrite steel without the addition of suitable filler material. Another investigation by Davies et al. [29] reported the mechanical properties of weld material in Aluminium TWBs at superplastic temperatures produced by TIG welding using AA5356 filler wire. Hideki et al. [21] attempted a process variation for TWB production. They applied electrical potential between plate and backside electrode during the CO_2 Laser welding of different thickness plates. The investigation concluded that the method was effective for increasing the bead root width; thus, enhance the welding speed and the butt joint gap tolerance. Michael et al. [22] investigated laser joining of Aluminium Titanium in the butt joint configuration and reported process development and mechanical properties along with FEM simulation. The investigation concluded that good tensile strength and therefore promising forming behaviour of the tailored blanks can be achieved in joining of dissimilar materials. Nishihara et al. [23] developed procedure for steel TWB produced by plasma arc welding and optimum welding speed and gap tolerance were determined. Yu Shu-rong [29] investigated into CO_2 Laser welding of different thickness plates of 5A06 Aluminium alloy. Another investigation into tensile properties of laser welded interstitial-free steel sheets of different surface conditions, galvanized and un-galvanized, and different thickness has been reported by Sushanta et al. [30]. Furthermore, the formability of the TWB had also been investigated and it was found that the overall formability was greatly influenced by the difference in thickness but the difference in surface condition has a very minor effect on the formality. Feasibility of TWBs manufacturing with newly developed process like friction stir welding process had also been investigated [25]. A recent investigation [12] reported improvement in mechanical performance of friction stir welded blanks of Aluminium alloy with different thicknesses.

It is evident from the past investigations that different processes and process variations have been attempted for TWB production. The main objective of the previous investigations has been to achieve the welds with sound mechanical properties through proper penetration and weld bead geometry. In order to achieve desired penetration, heat input is to be increased which eventually results in unwanted heat dissipation to the work piece. In case of different size, shape or materials of two parts to be welded, heat dissipation further becomes unequal in two parts due to difference material volume or properties in either in the sides of the weld. This unequal distribution may cause unwanted effects like distortion. Pulsed TIG welding is an advancement of conventional continuous TIG welding process that can control unwanted heat dissipation. Instead of supplying current at a fixed level as in case of conventional TIG welding, the Pulsed TIG welding comprises of two current levels namely peak current (I_P) and base current (I_B), as shown in Fig. 1.

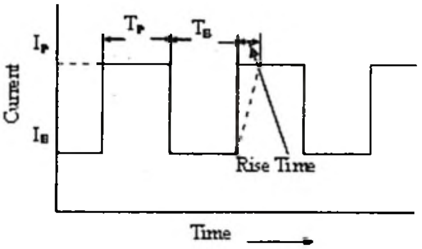

Fig. 1 Pulse parameters

The peak current is supplied for a small duration known as pulse duration (T_P). The base current acts for the remaining time duration known as base duration (T_B). The welding current switches between peak and base current. The total cycle time can be expressed as $T = T_P+T_B$ and in turn, pulse frequency can be express as the reciprocal of cycle time 'T'. The peak current, supplied for a short duration (pulse) that is expressed in terms of pulse width, $P_w = (T_P / T_P+T_B)$, facilitates rapid penetration, while base current acts for the remaining duration. The base current remains sufficient to prevent the arc from extinguishing but dose not perform any welding action. In this manner, unwanted heat dissipation to the work-piece can be controlled that may result in alteration in mechanical performance. This feature of the Pulsed TIG welding may be useful for dissimilar thickness welds. The moot point is if the Pulsed TIG welded joint can perform better in reference to the mechanical behaviour. Thus, the present investigation is intended to quantify the effect of Pulsed TIG welding process on the mechanical performance of Aluminium TWBs. Moreover, it is also be evaluated if the Pulsed TIG welding can alter the mechanical performance compared to the previously used process like conventional TIG welding. The subsequent section gives the experimental work carried out for realization of the above mentioned intention.

EXPERIMENTAL

In the present investigation, commercial Aluminium plates having dimensions 250x 75x 3 mm and 250x 75x 5 mm were welded with conventional and Pulsed TIG welding process. The groove angle between the plates was kept at 60 degree. Welding was carried out with alternating current (AC). Argon was used as a shielding gas and pure Aluminium rod of 3.15 mm (A-400) was used as a filler material. CEBORA 360 semi automatic machine was used for welding. In case of conventional TIG welding, the current was varied while in case of Pulsed TIG welding, pulse current, pulse frequency and pulse width have been varied. The range of process parameters was decided by conducting pilot experimentation and it has been ensured that parameters should result in sound welds on the basis of visual inspection. It was ensured that the final welds should not posses defects like burn-through, undercut, irregular ripples, lumps etc. Ranges for different experimental runs are shown in Table 1. Five mechanical properties, ultimate tensile strength (UTS), % elongation, hardness, fatigue life and impact strength were measured following the ASTM standards. The following section presents and discusses the results of the tests.

Table 1: Range of experimental parameters

Pulse frequency	50-200 Hz
Pulse current	210-270 Amp
Pulse width	0.3-0.7
Base current (Pulsed TIG)	150 Amp
Current (Conventional TIG)	210-270 Amp
Electrode size, material	4 mm, 2% Thoriated
Gas flow rate	10 lit/min
Travel speed	40 mm/min
Current Frequency	50 HZ

RESULTS AND DISCUSSION

The results of different mechanical tests are shown in Fig. 2 to 6. Effects of process parameter on UTS have been shown in Figure 2a and 2b. The Fig. 2a depicts variation in UTS due to change in peak currents and pulse frequencies.

It is evident that in case of Pulsed TIG welding, UTS increases with increase in peak current whereas on the same current level during conventional TIG welding (frequency 0 Hz), the reverse trend is observed. It is to be further noted that a substantial increase in the UTS is observed up to 230 A peak current during Pulsed TIG welding. With further increase in the current, the increment is not much significant. However, in general, higher pulse frequency results in higher UTS. It is to be further noted that at a given peak current during Pulsed TIG welding, increase in pulse frequency results in increase in UTS. Furthermore, variation in pulse frequency at lower peak current causes more variation in UTS. The results can be seen as a combined effect of peak current and frequency.

The peak current acts for a short duration that is sufficient for the arc to penetrate even with lesser heat dissipation to the surrounding plates. This phenomenon is known as 'arc seeing the bottom'. Due to this, proper fusion of plates and filler material occurs resulting in increment in UTS with peak current. However, at very high peak current the heat input to the weld metal increases which yield coarse grain and in turn a soft structure is observed. This compensates the above stated advantage achieved due to the peak current, thus, at higher peak current the UTS dose not significantly changes. The effectiveness of peak current can be obtained when it acts for a smaller duration. This observation can further be observed in the Fig. 2b that depicts variation in UTS due to change in pulse width and peak frequencies. A slight drop in the UTS is observed with increase in pulse width. At higher pulse width, the peak current acts for more time and the weld metal is supplied with extra heat, which unnecessarily is dissipated to surrounding material. This extra heat softens the weld material and results in marginal reduction in UTS with increase in pulse width as shown in Fig. 2b. The effect of the process parameters on UTS due to conventional TIG welding and Pulsed TIG welding can be observed in Fig. 2a. The difference in the behaviour of the conventional and the

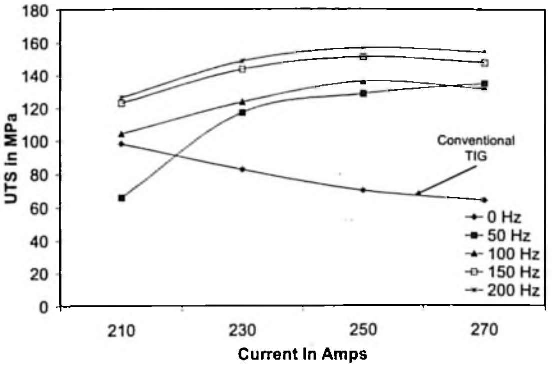

Fig. 2a Effect of peak current and frequency on UTS (Pulse width 0.5)

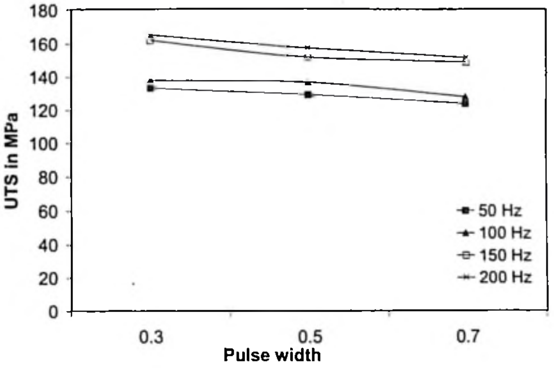

Fig. 2b Effect of pulse width and frequency on UTS (Pulse current 250 A)

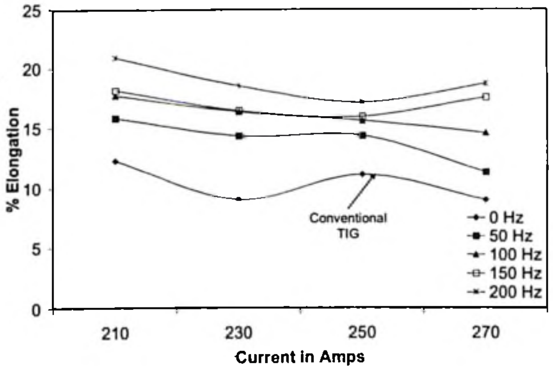

Fig. 3a Effect of peak current and pulse frequency on % elongation (Pulse width 0.5)

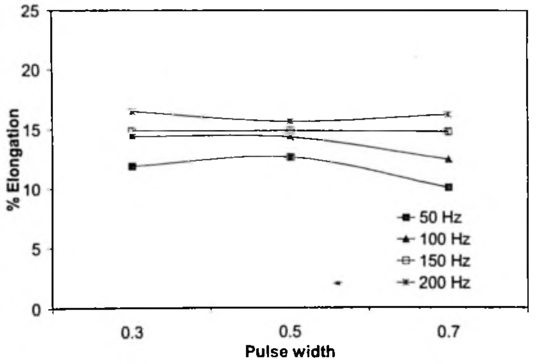

Fig. 3b Effect of pulse width and frequency on % elongation (Pulse current 250 A)

Pulsed TIG welding can be attributed to the fact that during the conventional TIG welding, the heat is continuously supplied that results in unwanted heat dissipation. Furthermore, heat distribution between plates remains non-uniform due to different thickness. This leads to varying solidification pattern and thus the weld itself acts as a source of nonconformity. This limitation is overcome by pulsation resulting in enhancement in UTS during Pulsed TIG welding. Consequentially other property like % elongation is also found to be enhanced by pulsation as shown in Fig. 3a and 3b.

It is evident that conventional TIG welding produces lesser % elongation compared to the Pulsed TIG welding. Moreover, higher frequency results in more % elongation. This result can be understood by the fact that pulsation results in grain refinement [33] that in turn increases the ductility. Thus, % elongation is affected by pulsation. Similarly, the hardness by-an-large follows the same trend as the previous properties. The effects of process parameters on hardness are shown in Fig. 4a and 4b. The conventional TIG welds have been found to produce lesser hardness. This result is in agreement with the previous observation with Pulsed TIG welding [34] that indicates higher hardness with tensile strength and ductility of weldments in the as-welded condition. It is to be noted that at higher current and higher frequency, a substantial dip in hardness is observed. A very high or a very low hardness is not sought in general. However, with help of Pulsed TIG welding a wider range of the hardness can be achieved and parameters can more freely be adjusted to attain desired hardness.

In case of toughness, the conventional TIG welding produces a level of toughness which is comparable to that

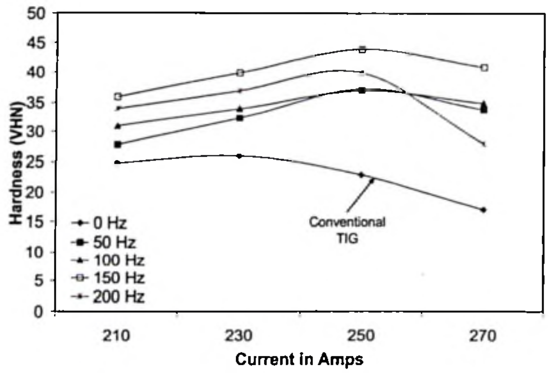

Fig.4a Effect of peak current and pulse frequency on hardness (Pulse width 0.5)

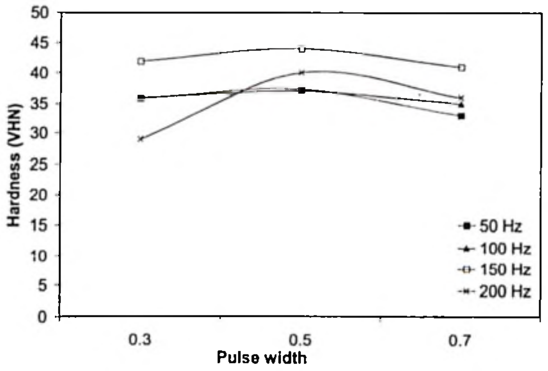

Fig. 4b Effect of pulse width and frequency on hardness (Pulse current 250 A)

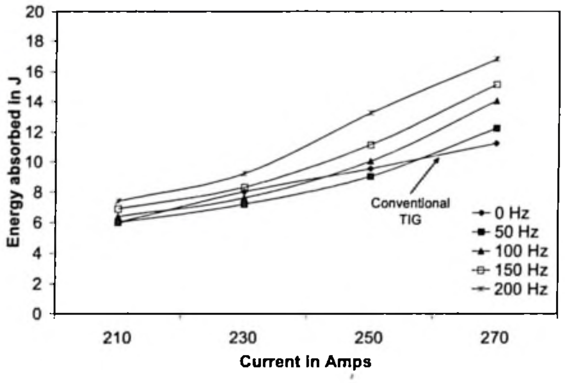

Fig. 5a Effect of peak current and pulse frequency on toughness (Pulse width 0.5)

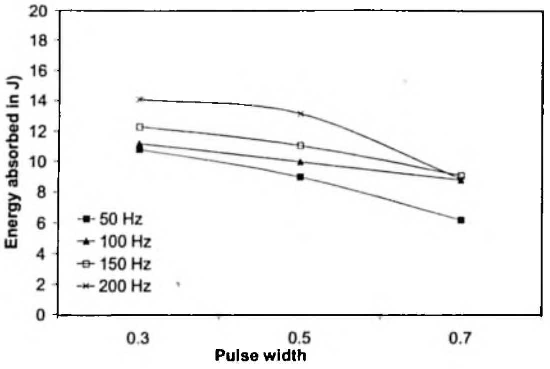

Fig. 5b Effect of pulse width and frequency on toughness (Pulse current 250 A)

produced only with Pulsed TIG welding at lower frequency as shown in Fig. 5a. At higher frequencies and higher current, Pulsed TIG welding results in higher toughness. As mentioned earlier, at higher pulse width, the peak current acts for more time and unnecessarily is dissipated to surrounding material. This extra heat softens the weld material and results in reduction in toughness with increase in pulse width as shown in Fig. 5b.

With fatigue life, an inverse relation ship between tensile strength and fatigue life is observed as shown in Fig. 6a and 6b. With increase in peak current the fatigue life has been found reducing contrary to the tensile strength which firstly increases and then stagnates. The fatigue life is affected by many reasons including microstructure, porosity, residual stress etc. As mentioned in [35], in spite of the absence of discontinuity defects and the presence of microstructure having desired ductility ensures a superior quality weld joint, however, residual stresses causes significant adverse influences like distortion, fatigue, corrosion, and stress corrosion cracking. Moreover, it is also known that the use of pulsed current improves weld quality especially with respect to its microstructure, porosity content, strength, and fatigue properties during welding at proper pulse parameters [35].

As mentioned earlier, the pulsed current ensures effective utilization of the heat, thus, there the residual stress must be controlled. This becomes more important in the dissimilar thickness welds which are more liable to residual stress and resulting lesser fatigue life. The increase in pulse width also results in reduction in fatigue life. It seems that the fatigue life during Pulsed TIG welding is affected by the local as well as global heat distribution in the vicinity of the weld joint and the experimental results indicates a simple observation of more the heat less the fatigue life. Nevertheless, the superiority of Pulsed TIG welding is observed in this case also. This can be verified from Fig. 6b that shows the conventional TIG welding can sustain less number of cycles before failure.

The result and subsequent discussion on the effect of process parameters on different mechanical properties of tailored welded blanks of dissimilar thickness establishes that the pulsation during welding can improve the mechanical performance. The current investigation further establishes that the range of process outcomes may be widened with Pulsed TIG welding. Apart from the controllable parameters used in conventional TIG welding, the Pulsed TIG welding is also controlled by more number of the process parameters. This provides the precise control over the process and simultaneously the unnecessary dissipation of the heat is also prevented. This phenomenon has been effectively used in the present investigation to improve the mechanical preference of the welded joint of dissimilar thickness that has been reported with continuous current in the past. The present investigation also lead to the possibility of the joining of dissimilar materials with Pulsed TIG welding that can be attempted in future.

CONCLUSIONS

The present paper demonstrated the effectiveness of Pulsed TIG welding for welding of dissimilar thickness welds. The conclusions that can be arrived at from the above discussion are as follows:

1. The Pulsed TIG welding undoubtedly improvises the mechanical properties in case of dissimilar thickness welds.
2. The application of Pulsed TIG welding provides more number of parameters to control the process, thus, the range of output is widened and the process becomes more versatile for various applications.
3. The above stated advantages are observed without any physical change like change in torch angle or deflection of arc by external means.
4. The study carried out during the present investigation can further be extended by adding more number of process parameters which have been kept constant during this investigation.

REFERENCES

1. Vogel F. , Mebus H. and Muller G., Layout and thickness optimisation of tailored blank designs with application in the automotive industries, Trends in computational structural mechanics, CIMNE, Barcelona, Spain, 2001
2. Irving B., Welding tailored blanks is hot issue for automakers, Welding Journal, 74, 1995, 49-52.
3. Pallett R. J. and Lark R. J., The use of tailored blanks in the manufacture of construction components, Journal of Materials Processing Technology, 117(1 -2) 2001, 249-254.
4. Merklein M. and Geiger M., New materials and production technologies for innovative lightweight constructions, Journal of Materials Processing Technology, 125-126, 2002, 532-536.
5. Richard W., John S. Vetrano, Mark T. Smith and Stan G. Pitman, Mechanical properties of aluminum tailor welded blanks at superplastic temperatures, Journal of Materials Processing Technology, 128, 2002, 3847
6. Arno Jambor and Matthias Beyer, New cars new materials, Materials and Design, 18 (4-6), 1997, 203-209.
7. Eisenmenger M., Bhatt K. K., and Shi M. F., Influence of Laser Welding Parameters on Formability and Robustness of Blank Manufacturing: An Application to a Body Side Frame,' SAE Technical Paper Series, Paper No. 950922, 1995, 171182.
8. Anna Kochan, Laser welding adapts to non-linear tailored Blanks, Assembly Automation, 21(1) 2001, 48-50
9. Yasunobu Miyazaki, Koji Hashimoto, Yukihisa Kuriyama and Junichi Kobayashi, Welding Methods and Forming Characteristics of Tailored Blanks (TBs), Nippon Steel Technical Report No. 88 JULY 2003, 39-43
10. Muchihara and Kfukul, Performance of tailor welded blanks using automotive high strength steel sheets for practical use. Study of tailor welded blanks using automotive high-strength steel sheets (2nd report), Welding International, 20 (8) 2006, 622632.
11. Tusek J., Kampus Z. and Suban M., Welding of tailored blanks for

different material, Journal of Material Processing, 199, 2001, 180-184.

12. Fratini L., Buffa G. and Shivpuri R., Improving friction stir welding of blanks of different thicknesses, Materials Science and Engineering: A, 459(1-2), 2007, 209-215.
13. Zhao K. M., Chun B. K. and Lee J. K., Finite element analysis of tailor-welded blanks, Finite Elements in Analysis and Design, 37(2), 2001, 117-130.
14. Scott D. Raymond, Peter M. Wild and Christopher J. Bayley, On modeling of the weld line in finite element analyses of tailor-welded blank forming operations, Journal of Materials Processing Technology, 147(1), 2004, 28-37.
15. Bayraktar E., Isac N. and Arnold G., An experimental study on the forming parameters of deep-drawable steel sheets in automotive industry, Journal of Materials Processing Technology, 162-163, 2005, 471-476.
16. Cheng C.H., Jie M., Chan L.C. and Chow C.L., True stressstrain analysis on weldment of heterogeneous tailor-welded blanksa novel approach for forming simulation, International Journal of Mechanical Sciences, 49(2), 2007, 217-229.
17. Qiu X.G., Chen W.L, The study on numerical simulation of the laser tailor welded blanks stamping, Journal of Materials Processing Technology, 187-188, 2007, 128-131.
18. Youngmoo Heo, Youho Choi, Heon Young Kim, Daegyo Seo, Characteristics of weld line movements for the deep drawing with drawbeads of tailor-welded blanks, Journal of Materials Processing Technology, 111, (1-3), 2001, 164-169
19. Chung B. G., Rhee S., Lee C. H., The effect of shielding gas types on CO_2 laser tailored blank weldability of low carbon automotive galvanized steel, Materials Science and Engineering A, 272(2), 1999, 357-362.
20. Ana Reis, Pedro Teixeira, Ferreira Duarte J. , Abel Santos, Barata da Rocha A. and Fernandes A. A., Tailored welded blanksan experimental and numerical study in sheet metal forming on the effect of welding, Computers & Stru-ctures, 82, (17-19), 2004, 1435-1442.
21. Hideki Hamatani, Yasunobu Miyazaki, Masahiro Ohara, Effect of applying electrical potential to a CO_2 laser welding of different thickness plates, Science and Technology of Advanced Materials, 6(6),2005, 712-719.
22. Michael Kreimeyer, Florian Wagner and Frank Vollertsen, Laser processing of aluminum-titanium-tailored blanks, Optics and Lasers in Engineering, 43(9), 2005, 1021-1035.
23. Nishihara Tatsuo, Kuroda Akihiro, Yamauchi Ryo and Warashina Takayasu, Development of Plasma Arc Welded Tailored Blanks for the Front Pillar Inner, Suzuki Tech Rev, 32, 2006, 45-50
24. YU Shu-rong, Fan Ding, Xiong Jin-hui and Chen Jian-hong, CO_2 laser welding of 5A06 aluminum alloy plates with different thicknesses, Transactions of Nonferrous Metals Society of China, 16, 2006, 1407-1410.
25. Buffa G., Fratini L., J. Hua and Shivpuri R. , Friction Stir Welding of Tailored Blanks: Investigation on Process Feasibility, CIRP Annals - Manufacturing Technology, 55(1), 2006, 279-282.
26. Venkat S., Albright C. E., Ramasamy S., and Hurley J. P., CO_2 laser beam welding of aluminum 5754-O and 6111-T4 alloys, Welding Journal, 76(7), 1997, 275s-282s.
27. Davies R.W., Oliver H.E., Smith M.T. and G.J. Grant, Characterizing Al tailor welded blanks for automotive applications, Journal of the Minerals Metals & Materials Society , 51 (11), 1999, 46-50.
28. Davies R. W., Smith M. T., Oliver H. E., Khaleel M. A. and Pitman S.G., Weld Metal Ductility in Aluminum Tailor Welded Blanks, Metallurgical and Materials Transactions A, 31(11), 2000 , 2755-2763.
29. Richard W. Davies, John S. Vetrano, Mark T. Smith and Stan G. Pitman, Mechanical properties of aluminum tailor welded blanks at superplastic temperatures, Journal of Materials Processing Technology, 128, (1-3), 2002, 38-47.
30. Sushanta Kumar Panda, Ravi Kumar D. , Harish Kumar and A.K. Nath, Characterization of tensile properties of tailor welded IF steel sheets and their formability in stretch forming , Journal of Materials Processing Technology, 183, (2-3), 2007, 321-332.
31. Atsushi Seto, Toyoki Yamamoto, Toshiyuki Niwa, Influences of loading direction and thickness ratio on fatigue properties of

tailored welded blanks, International Journal of Fatigue, 29(4), 2007, 729-737.

32. Bayraktar E., Kaplan D., Yilbas B.S., Comparative study: Mechanical and metallurgical aspects of tailored welded blanks (TWBs), Journal of Materials Processing Technology, 204(1-3), 2008, 440-450.

33. Sharir Y, Pelleg J, Grill A. Effect of arc vibration and current pulses on microstructure and mechanical properties of TIG tantalum welds, Metals Technology, 5 (6) 1978, 190 -194.

34. Kishore Babu N., S. Ganesh Sundara Ramana, Mythilib R. and S. Sarojab, Correlation of microstructure with mechanical properties of TIG weldments of Ti6Al4V made with and without current pulsing, Materials Characterization, 58(7), 2007, 581-587.

35. Ghosh P. K. and Ghosh Aritra K., Control of residual stresses affecting fatigue life of Pulsed current gas-metal-arc weld of high-strength aluminum alloy, Metallurgical and Materials Transactions A, 2004, 2439-2444.

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