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Short Communication

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Influence of Longitudinal Scratch Defects on the Bendability of Titanium Alloy

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ABSTRACT

Post-manufacturing induced defects in the form of scratches are sometimes inadvertently introduced onto sheet metal surfaces during either transportation, storage or handling. However, limited research has been previously carried out to establish the impact of such surface defects on sheet formability. Test trial results after press brake forming of Ti-3Al-2.5V showed that for longitudinal scratches oriented along the sheet rolling direction, scratch profiles with depth in the ranges of -1μm to -18μm and pile up height between 1μm to 16μm can be successfully formed; hence could be deemed acceptable during the sheet selection process. Failure of the coupons during the press brake forming trials was due to the impact of the scratch defects in their role as stress raisers and occurred primarily at the longitudinal scratch defect zones.

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Article Highlights

- Scratch defects instituted on sheet metal surfaces influence the cold formability of Ti-3Al-2.5V in their role as stress concentration sites for crack nucleation. However, the experimental trials conducted uncovered a limit of scratch characteristic profile below which sheets with scratch defect surfaces could be deemed acceptable for adoption in a press brake forming operation.
- The nature of the tool geometry impacts on the sheet bendability and are significantly responsive to the nature of the scratch defect profile.
- This article provides vital information which could be useful during material selection processes for sheet forming by clarifying the requirements for supplied sheets. The results could also help in the improvement of the room temperature formability of titanium alloys through the optimization of surface conditions for forming operation.

Introduction

Sheet metal surface defects could be encountered at various stages of a material fabrication process. Defects such as inclusions, oxide lines, thermal cracks, scars and blowholes may be produced during material production. Such surface defects would normally deteriorate the material mechanical properties [1]. If not controlled such defects may lead to poor surface integrity of finished parts and high production cost in terms of rejected components [2]. The high cost incurred in correcting post- production surface defects has led to the formulation of various optimization techniques such as; the one-shot deflectometry technique based on the Fourier- transform method, development of a genetic algorithm which relies on extreme machine learning, convolutional neural network system for recognition and detection and an image thresholding method based on automated vision systems [3-6]. These optimization techniques help in detecting and correcting the defects attained during production. Other sheet metal post-processing surface defects in the form of grooves, indents and scratches are sometimes inadvertently instituted onto sheet metal surfaces during transportation, storage or handling on the workshop floor (Figure 1c). Surface defects like scratches are mostly produced due to bad friction conditions between contact surfaces [7]. For exceptional cases where sheet surface conditions prior to forming are strict, sheets with such pronounced surface defects may be rejected outright. Otherwise, such defective sheets may be employed in forming parts. However, research directed at ascertaining the direct impact of such post- manufacturing induced sheet surface defects on material forming capability has not been extensively reported. Considering the high sensitivity of titanium to notches and surface inhomogeneity, there is the need to examine the impact of sheet metal scratch defects on their room temperature formability. In the present work, press brake forming trials were undertaken to assess the effect of post-manufacturing induced sheet surface scratch defects on the bendability of titanium alloy.

Experimental Procedure

The Material

The material studied in this research was Ti-3Al-2.5V with a thickness of 1.6mm. Ti-3Al-2.5V, sometimes referred to as ‘half Ti-64’, is a near α alloy with an intermediate strength and good cold formability. It is usually employed in aerospace applications such as hydraulic tubing systems and lightweight honeycomb structures.

Press Brake Forming Trials

The coupons for the press brake forming were categorised into three distinct surface profile threshold ranges (scratch designations A, B and C) as shown in Table 1. Scratches on either side of the coupons were measured using the Alicona 3D optical measurement system. The working principle of this microscope is based on the combination of the small depth of focus with vertical scanning in order to obtain the topography of the region of focus (Figure 1b). For the coupon surfaces measured, only the highest defect profile (see Figure. 1a) values were considered. Only coupons with longitudinal scratches oriented along the sheet rolling direction were considered. For each category of surface scratch profile range, 30 coupons were assessed during the press brake forming trials for each punch nose radius.

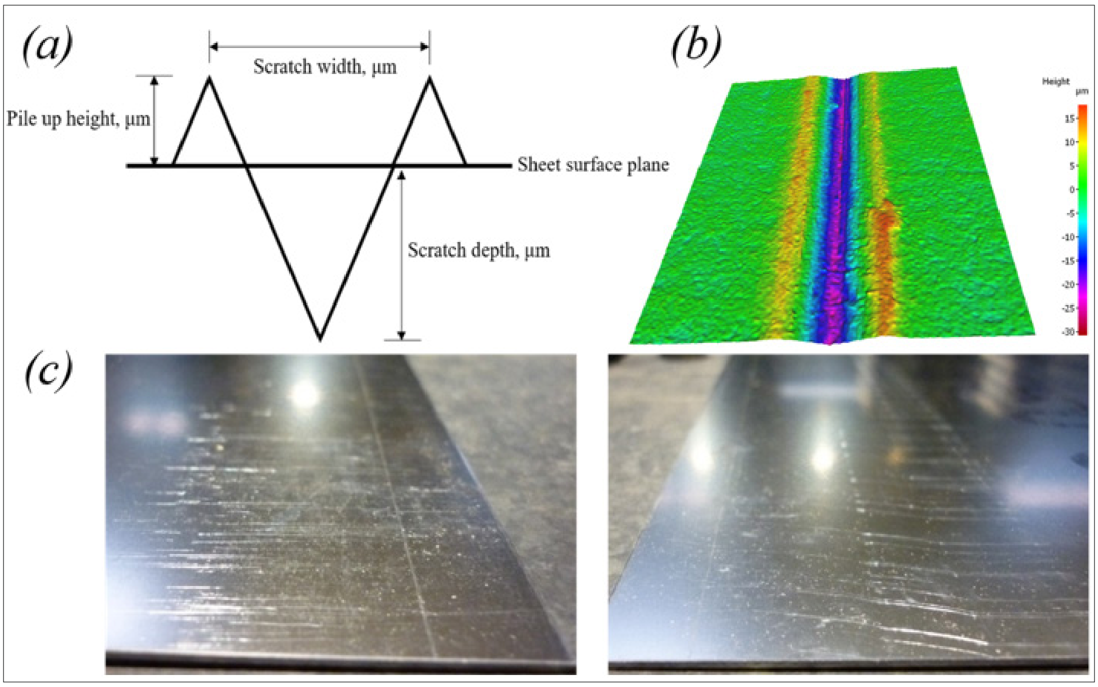

Figure 1: Ti-3Al-2.5V sheet metal surface condition

Table 1: Three ranges of scratch profiles examined during the press brake forming

Scratch designation	Depth, µm	Pile up height, µm
A	-1 to -18	1 to 16
B	-18 to -35	16 to 35
C	-35 to -80	35 to 50

Figure 2 shows the experimental set-up for the press brake forming trials. The press brake forming trials were conducted using a Jean Perrot Maneo 105/30 CNC hydraulic press-brake machine equipped with a maximum stroke of 250mm and a maximum capacity of 1000kN. A Wila made standard premium OZU-353 515 die with radius =3.5mm (16×300), height = 100mm was used together with two different punch nose radii dimensions; a BIU-231 515 punch with radius =3mm (280), height =200mm and a BIU-031 100 punch with radius =1mm (280), height =200mm. In order to ensure that the coupons were formed to their optimum bending angle, the radius of the die was chosen to be slightly larger than the punch radii. Two different punch nose radii was chosen to compare the material response to two bending angels as well as to ensure the attainment of tighter radii prior to failure. For the press brake forming trials, 180 rectangular coupons of dimension 300×40mm with longitudinal scratches oriented along the sheet rolling direction were prepared using a guillotine metal cutter. Prior to the bend-test, the tool alignment was checked with a laser source. The coupon was then placed over the open die and aligned in position with the aid of a robotic arm. After setting the automated control on the computer numerical control (CNC) panel with the material and tool parameters, the coupon was then pressed by the punch to the optimum radius to execute the press forming manoeuvre.

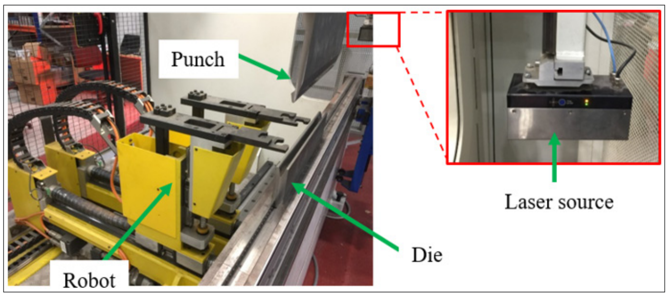

Figure 2: Experimental set-up for the press brake forming trials

Results and Discussion

Table 2 shows the results after press brake forming of the test coupons deformed with two different punch nose radii. The test criteria adopted in this research to ascertain the impact of the scratch characteristic profile is the failure or success of the test trial. Failed coupons after the test trials were characterised by cracks at the summit of the V-bend, whereas successful trials were fully bent per the punch radius adopted without crack occurrence. Test trials for the coupons with no scratch defect (defect free surface) exhibited 100% forming success rate after bend forming with both punch radii. For longitudinal scratches deformed with a 3mm radius nose punch, scratches with a depth in the ranges of -1μm to -18μm and a pile up height in the ranges of 1μm to 16μm were successfully formed without failure.

Table 2: Press brake forming trials for different longitudinal scratch profiles

Punch nose radius = 1mm				
Scratch designation	**Total trials**	**Pass**	**Fail**	**Success rate, %**
A	30	26	4	87
B	30	12	18	40
C	30	0	30	0
Punch nose radius = 3mm				
A	30	30	0	100
B	30	16	14	53
C	30	0	30	0

For scratch profiles with depth in the ranges of -18μm to -35μm and a pile up height between 16μm to 35μm, the forming success rate reduced by half the initial threshold when deformed with the 3mm radius punch nose. Scratch profiles with the scratch designation 'C' were 100% unsuccessful, when deformed with both punch nose radii. The success rate for all scratch profile designations also reduced for coupons deformed with the punch nose radius of 1mm compared to a punch nose radius of 3mm. This observation could be attributable to the fact that a smaller punch radius exerts more pressure on the contact sheet surface since it occupies a smaller surface area. This permits larger force per unit contact area leading to higher stress concentration and early material yielding, leading to early fracture. Conversely, a punch with larger nose radius produces a broader contact area with minimised force thereby resulting in delayed material yielding. Similar press brake forming test trials were conducted by Määttä et al., on ultra-high strength steels (direct quenched bainitic-martensitic steel DQ960 and abrasion resistant steel AR500- due to their sensitivity to surface defect e.g. scratches) with surface cracks produced with laser ablation in order to ascertain the critical surface defect size which results in failure during press brake forming. Their work found that the critical crack sizes attained were responsive to the material hardness and that about 36% reduction in the material hardness resulted in the critical crack size increasing by 138% [8].

Material failure during the press brake forming trials occurred mainly at the longitudinal scratch defect sites. The macro-cracks (green arrows) were observed to develop away from the coupon machined edges (Figure 3a). The macro-cracks were also seen to have occurred along the trajectory of the longitudinal surface scratches. This indicates that the main cause of the coupon failure could be attributable to the effect of the longitudinal scratch defects (red arrows)-in their role as stress raisers (Figure 3a). Analysis of the micro-features of the scratch surface (blue arrow) after the press brake forming trials revealed regions of micro-crack initiation (yellow arrow)- Figure 3b. This is opposed to observations made by Reyes et al., [9] on AA7108 T6 aluminium alloy during press forming, where the failure crack was observed to commence from the sample fabricated edges with traces of orange peel seen just outside the fracture region [9].

Additional press brake forming trials are being conducted on other titanium alloys to foster the formulation of predictive models that could be exploited industrially for clarifying requirements for supplied sheets and material selection purposes for forming operation.

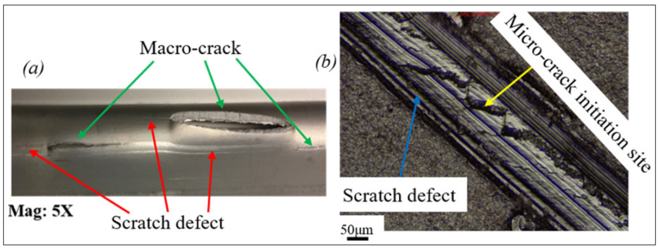

Figure 3: Nature of the crack nucleation process after press brake forming with either punch
(b) Macro and (b) micro-crack occurrence

Conclusion

Posts manufacturing induced defects in the form of scratches are sometimes inadvertently introduced onto sheet metal surfaces during either storage, handling or transportation of sheets. For forming operations with uncompromising requirements on the integrity of supplied sheets, materials with such post manufacturing induced surface defects may be rejected. However, the actual influence of such post-processing induced surface defects on the forming capability of sheet metals has not been extensively investigated.

Press brake forming trials were conducted on Ti-3Al-2.5V coupons with surfaces of varied longitudinal scratch defect profiles. The work found that;

- Press brake forming trials conducted on the coupons with a defect free surface exhibited 100% forming success rate after V-bending with both 1mm and 3mm punch radii. For longitudinal scratches oriented along the sheet rolling direction, scratch profiles with depth in the ranges of -1μm to -18μm and pile up height between 1μm to 16μm can be successfully formed under room temperature conditions. Also, scratch defects with the depth ranges of -18μm to -35μm and a pile up height between 16μm to 35μm could be formed to an appreciable extent with the probability of failure of about a half that of the former depth range. However, scratch profile dimensions beyond the stated threshold values resulted in formed part failure and may be rejected for use in forming operations for the material and sheet thickness studied.
- The punch nose radius has a significant impact on the bendability of the sheet metal. Thus, the dimensioning of the tool geometry influences the bending capability as well as the sheet surface defect response of the material.
- Failure during the press brake forming trials occurred primarily at the longitudinal scratch defect zone. The surface cracks were detected to have emanated away from the coupon fabricated edges and travelled along the path of the longitudinal surface scratch defect. The fracture initiation was as a result of the impact of the longitudinal scratch defects in their role as stress raisers. This observation was supported by the presence of micro-crack nucleation sites at the longitudinal scratch defect surface after the press brake forming trials.

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Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest

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