THE EXAMINATION OF THE CAUSES OF THE OCCURRENCE OF PROTRUSION DEFECTS IN A CAR BONNET PANEL

KRAWCZYK Janusz[1], PAWŁOWSKI Bogdan[1], BAŁA Piotr[1,2], PAĆKO Marek[1], ŚLEBODA Tomasz[1], CIOS Grzegorz[2], FROCISZ Łukasz[1], STĘPIEŃ Milena[2]

AGH University of Science and Technology, [1]Faculty of Metals Engineering and Industrial Computer Science, Cracow, Poland, EU
[2]Academic Centre for Materials and Nanotechnology, Krakow, Poland, EU, jkrawcz@agh.edu.pl

Abstract

This paper presents the research focused on surface defects of galvannealed car body sheets. The fragments of a car bonnet panel after press forming as well as steel sheet used for its production in as-delivered condition (prior to press forming) were investigated. The fragments of the sheet at the beginning, center and end of a coil and also from the left side, center and the right side of steel bandwidth were studied. The assumed scope of studies has covered the investigations of zinc coating morphology, studies of zinc adhesion, steel sheet material formability tests, scratch tests, defects analysis, and analysis of steel sheet material in terms of its usability for zinc coating. The fragments of a car bonnet panel were cut out in the spots where defects, i.e. protrusions, have been found. Defects defined as protrusions occurred as a result of particle or particles conglomerate depositing on the surface of the die. Particles causing protrusions were identified both as steel fragments most likely originating from steel sheet sheared by the edge of the die, and fragments of spalled zinc coating, most likely in the form of conglomerates. Moreover, the chemical composition of steel, especially too large silicon content, may also be the reason of easier spalling of fragments of zinc coating. The investigations also showed, that non-woven fabric used for cleaning the dies surface contained the particles, the presence of which on the surface of the dies can be considered as the origin of defects.

Keywords: Galvannealing, car body sheets, press forming, zinc coating

1. INTRODUCTION

BH (Bake Hardening) steels are used for stamping of car body parts [1-3]. Zinc coating is applied for protecting BH steel sheets [4-6]. Spalling of zinc protective coating may occur during stamping [7, 8]. Such spalling strongly depends on protective coating morphology [9-11], which is often influenced by so called “the Sandelin effect” [12-14]. This phenomenon can be limited by the application of alloying elements such as Al, which can contribute to the formation of the protective interlayers [14-16].

The conception of the complex mechanism of the formation of the protrusion defects during stamping of car bonnet panel was presented. Basing on the results of this research, the factors promoting formation of such defects were determined.

2. MATERIAL FOR THE INVESTIGATIONS

The following materials were provided for the studies:

- The fragments of car bonnet panel after press forming (**Figure 1a**).
- Non-woven fabric which was used for cleaning the surface of the dies, containing the particles, the presence of which on the surface of the dies was considered as the cause of protrusions (**Figure 1b**).
- The fragments of panel cut out in the spots where defects, i.e. protrusions, were found (**Figure 1c**).

- The fragments taken from the die impressions before press forming. The fragments of the sheet taken from the start of a coil, in the center of a coil and from the end of a coil and also from the left side, center and the right side of the panel (**Figure 1d**).

The investigations were performed on three tested materials produced from the same steel grade (**Figure 2**).

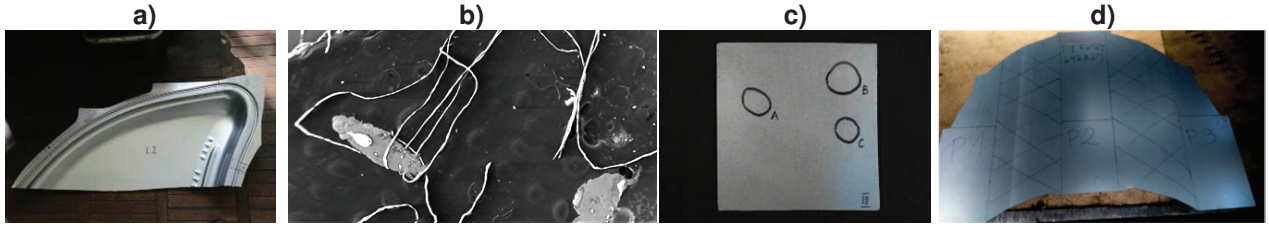


Figure 1 Exemplary material for investigations

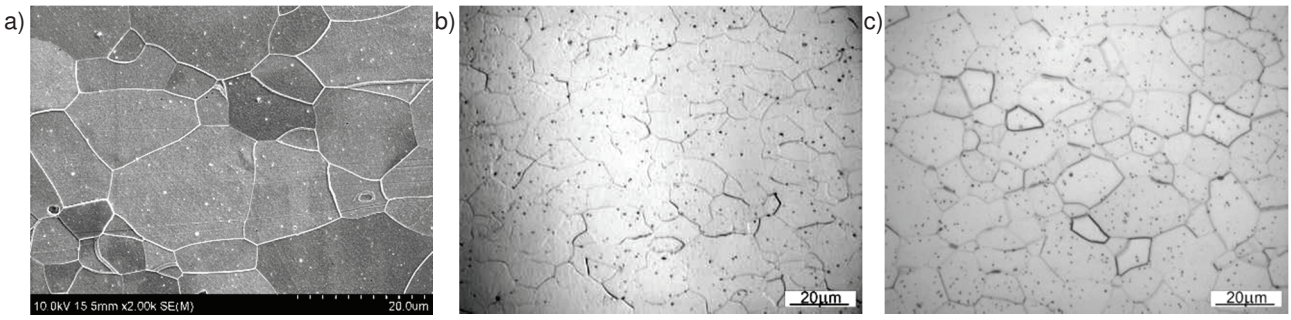


Figure 2 The microstructure of steel sheet: a) material I - SEM, b) material II - LM, c) material III - LM

3. RESULTS AND DISCUSSION

Local cavities on the lower surface of the deep drawn steel sheet can be observed (**Figure 3a, b**). Loose fine particles were also observed on this surface (**Figure 3b, c**). The size of these particles corresponds to the size of the occurring cavities. Similar particles were found on non-woven fabric used for cleaning the stamping dies. Bigger particles were identified as the fragments of deep drawn steel sheet (**Figure 4)**. The microanalysis of fine particles (occurring in a much larger quantity) showed, that they came from zinc layer (**Figure 5)**. While large particles are likely the fragments formed during the shearing operation, fine particles spalled from the surface of the processed steel sheet. The exemplary area of such zinc spallation is shown in **Figure 6**. As can be noticed, decohesion of the zinc layer propagates to the surface of the steel sheet.

The comparison of steel sheet II (less protrusion defects on the surface of steel sheet after stamping) and III (more protrusion defects) before stamping operation was performed to evaluate the influence of zinc coating morphology on its spallation. **Table 1** shows the chemical compositions (the chemical composition of cast material) of steel sheet II and III. As can be noticed, these materials differ mainly in silicon and phosphorus content. Steel sheet III has higher content of both those chemical elements. In both cases it is the chemical composition of BH steel.

The morphology of zinc coating on steel III is shown in **Figure 7**. As can be observed, the continuity of interlayers between zinc coating and steel sheet cannot be noticed in this case. The analysis of chemical elements distribution in coatings on steel sheets II and III showed the presence of interlayer rich in Al (**Figure 8**). Moreover, in the case of steel sheet II this interlayer maintains its continuity.

The chemical composition of steel sheets and continuity of interlayer rich in Al result in better resistance of steel sheet having continuous interlayer and lower Si and P content to spallation during the performed scratch tests (**Figure 9**). The content of Si in steel sheet III is different in various areas of steel coil (**Figure 10a**). It influences the spallation of the zinc coating during Erichsen tests (**Figure 10b** - dotted line).

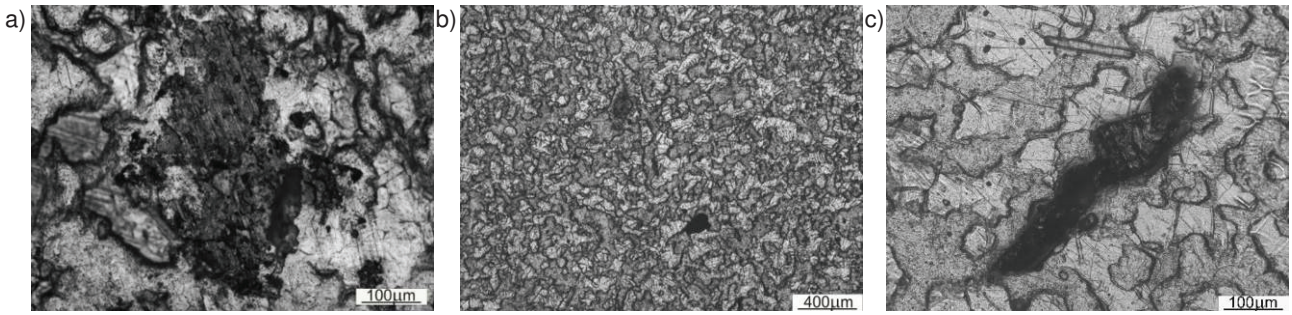
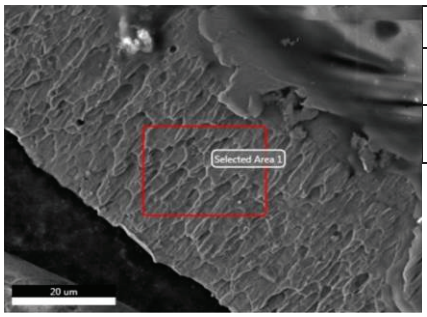
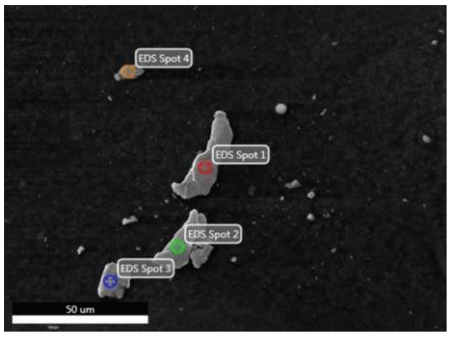


Figure 3 The areas of the occurrence of the protrusion defects (a, b) and particles causing such defects (c) on the surface of steel sheet after stamping: a) material I, b, c) material III



Area 1	weight %	atomic %
Mn (K)	0.44	0.46
Fe (K)	99.56	99.54

Figure 4 The result of the microanalysis of big particle taken from the stamping die surface



	element	weight %	atomic %
Spot 1	Al (K)	0.2	0.4
	P (K)	0.6	1.3
	Zn (K)	99.2	98.3
Spot 2	Zn (K)	100	100
Spot 3	Zn (K)	100	100
Spot 4	Al (K)	0.3	0.8
	Cl (K)	0.6	1.1
	Zn (K)	99.1	98.1

Figure 5 The result of the microanalysis of fine particles taken from the stamping die surface

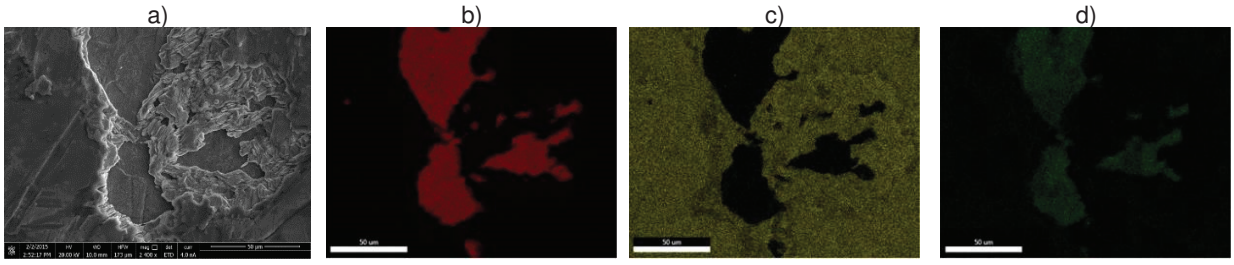


Figure 6 The analysis of chemical elements distribution in the area of spallation occurred on the surface of steel sheet I after stamping: a) SEM image, b) Fe, c) Zn, d) Al

Table 1 The chemical composition (wt. %) of steel sheet II and III

Material	Fe	C	Si	Mn	P	S	Ti	Al	Nb
II	Bal.	0.003	0.004	0.435	0.038	0.010	0.009	0.031	0.007
III	Bal.	0.003	0.040	0.320	0.063	0.006	0.001	0.035	0.009

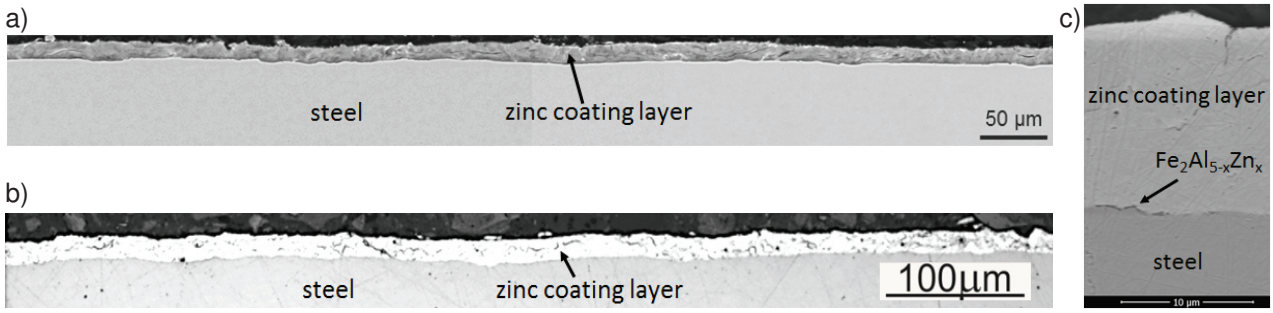


Figure 7 The morphology of zinc coating on steel sheet III: a) SEM image, b) light microscope, c) SEM image

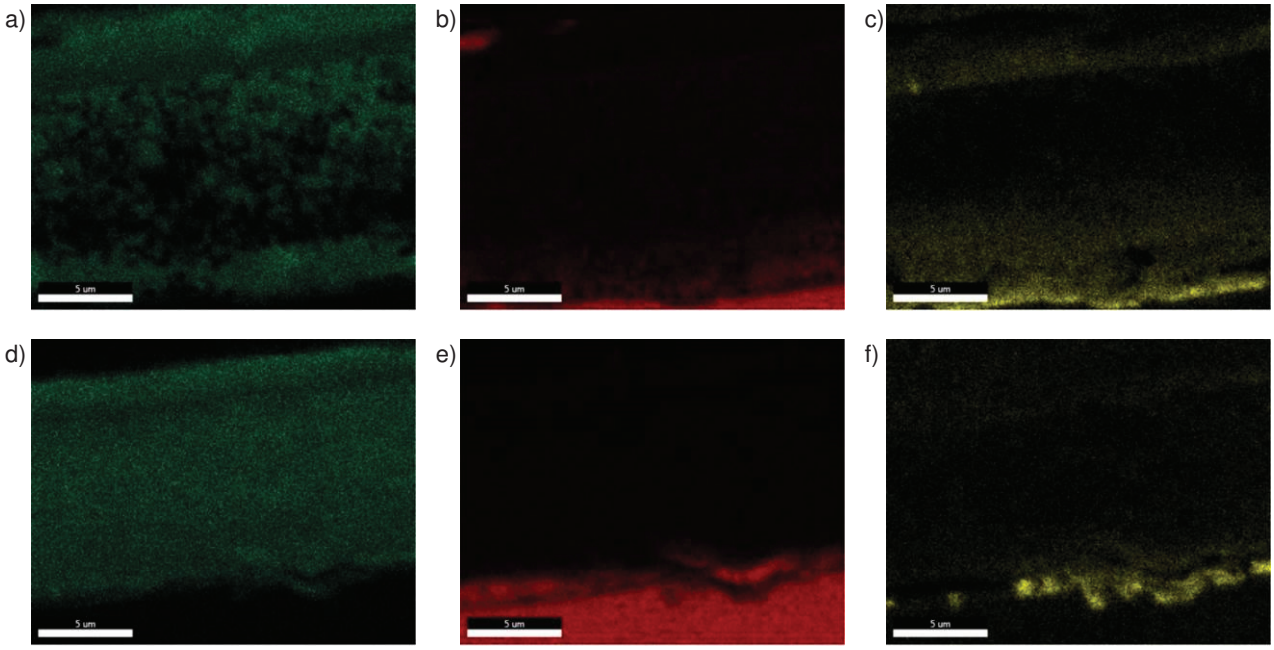


Figure 8 The analysis of the chemical elements distribution (a, d - Zn, b,e - Fe, c,f - Al) on the cross-section of zinc coating on the surface of steel sheet II (a-c) and III (d-f)

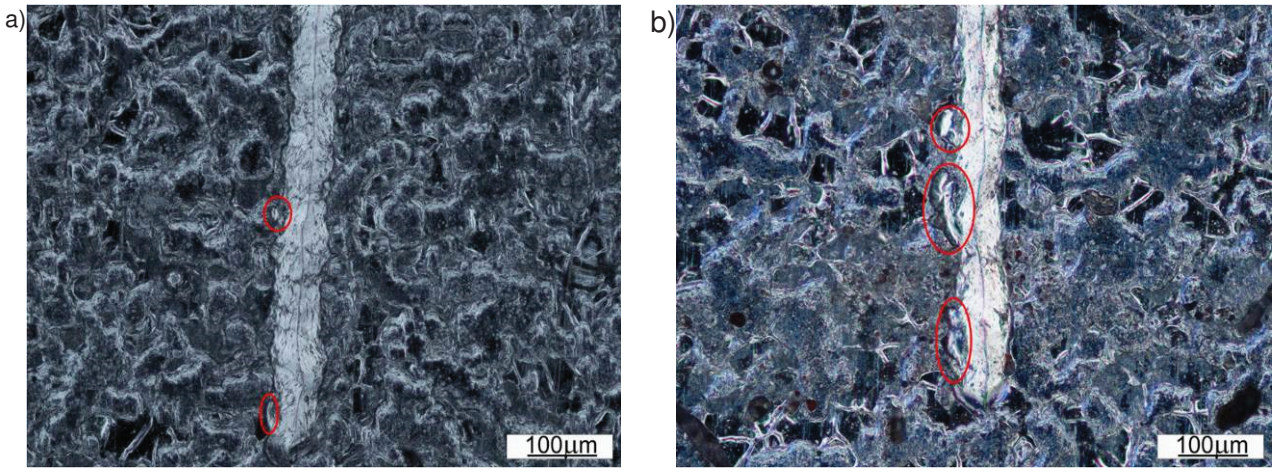


Figure 9 The results of the scratch tests for: a) material II, b) material III.
The areas of spallation were marked.

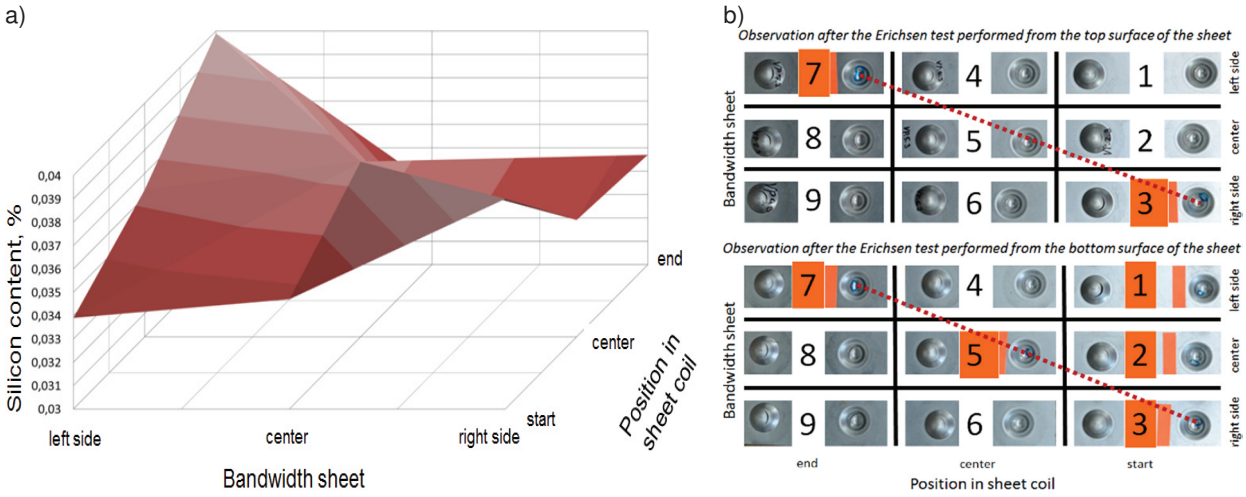


Figure 10 Distribution of Si content (a) in steel sheet III and corresponding location of zinc coating spallation (coloured) after Erichsen test (b)

4. CONCLUSIONS

Based on the delivered testing material and the performed tests the following conclusions can be drawn:

1) Particles causing protrusions were identified as steel fragments, most likely originating from the edge of the die sheared sheet, and also fragments of spalled zinc coating (most likely in the form of conglomerates, mainly originating from drawbead areas - **Figure 11**).

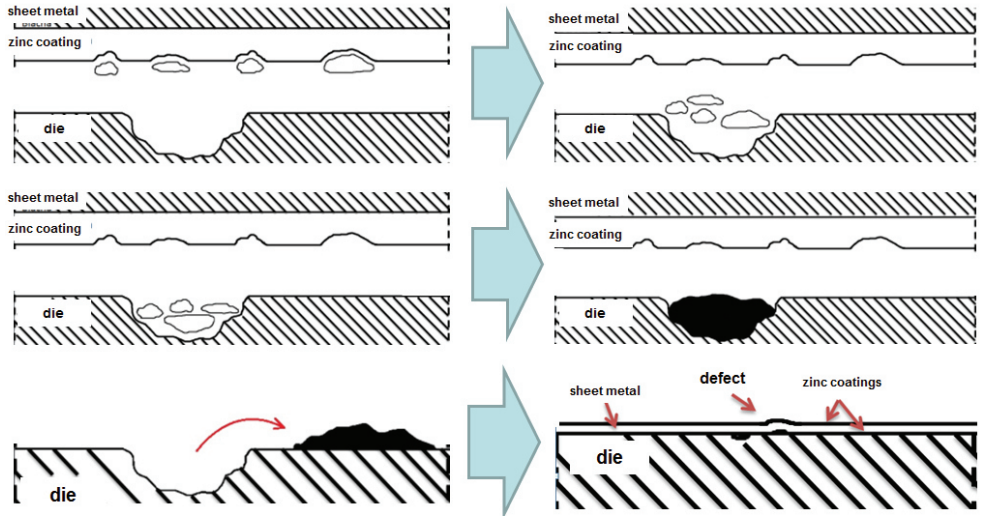


Figure 11 Schematic representation of the subsequent stages of protrusion defects formation

2) The increased Si and P content in steel sheet as well as local lack of continuity of rich in Al interlayer facilitate spallation of zinc coating.
3) It is necessary to control the chemical composition of steel sheets delivered for the stamping process so it should not exceed 0.03% of Si.
4) It is necessary to clean the steel sheet (e.g. by means of air stream) before press forming, including the cutting edge in particular.
5) Due to high probability of formation of protrusions caused by an impact of conglomerates of fine particles spalled from the zinc coating, it is necessary to resign from cleaning the surfaces of the dies by means of a soaked unwoven fabric. It should be replaced by the methods which do not introduce agents

facilitating formation of the above mentioned conglomerates. At this point it is necessary to pay attention to the occurrence of protrusion defects on the surface of a die, where particles of zinc coating may accumulate, and next relocate to the die shaping surface, which finally results in formation of protrusions on the sheet being formed. This mechanism of formation of protrusions is characterized by the difficulty in determining which of the shaped materials was defective, because the defects may be revealed only after shaping the material with proper adhesion of zinc coating.

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