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EFFECT OF TYPE AND THICKNESS OF PAINT FILM ON THE FORMING OF GALVANIZED STEEL SHEET IN MOBARAKEH STEEL COMPANY (MSC)

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A B S T R A C T

Formability is on of the most important factors for pre-painted steel sheets (PCMs). In this study, tensile and formability properties of painted galvanized steel sheet with different thickness were investigated by tensile and deep drawing test, and the relationship between type and thicknesses of paint coated on the galvanized steel sheet with formability PCMs after deep-drawing were studied. Forming limit diagrams (FLDs) have been evaluated experimentally by stretch-forming sheet samples over a hemispherical punch. The effect of thickness of paint film on formability has been analyzed by using galvanized steel sheets that coated with different thickness of polyester and plastisol paint, and a comparison has been made with an uncoated galvanized steel sheet. The presence of resin in paint film appears to have a dominant role to decrease of coefficient of friction between punch and sheet. We found that with increasing of paint thickness in PCM, coefficient of friction between punch and sheet has been decreased. With decreasing of coefficient of friction between punch and sheet, formability of PCM could be better. Due to presence of PVC particle plastisol paint, galvanized steel sheet that coated with plastisol paint have better formability than polyester paint.

INTRODUCTION

Coil coating first appeared in the 1940, however, its root can, nevertheless, be traced back to the architectural movements which occurred at the beginning of the twentieth century. It was at this time that the use of steel in construction developed and soon steel structures were painted to beatify and afford distinction. In the years to follow, techniques and paints was developed enabling the profession of pre-coating metal to become establishing [1].

Coil coating really took off in the United States in the 1950s.both architecture and electrical household goods industry now looked to these new combinations of painted steel or aluminum. During the 1960s, lines reached speeds of 75m/min with width of 1.50 m. In 1962, production reached a turnover of 460,000 tonnes (290,000 tonnes of steel and 170,000 tonnes of aluminum) and the following year, two coat lines were introduced for galvanized steel. In 1966, the United States had 90 modern coils coating lines and produced more than 500,000 tonnes per year. Thirty-three years later, there were some 180 lines (steel and aluminum combined) which produced 4.2 million tones of coated metal [1]. Pre-painted steel sheets (Fig.1) (PCM) are manufactured in a sheet or coil coating line and processed and assembled in factories making household electric appliances, building materials and other [2].

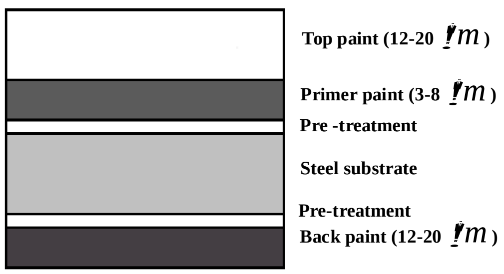

Fig.1. Typical structure of pre-coated steel sheet [2]

In these factories, painting process can be eliminated by using PCM thereby the problem of hazard to health and

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area pollution by solvent evaporation by solved. Elimination of the paint process also offers other advantages such as improved productivity, and thus the use of PCM has been expanding recently, common and a study of the formability of PCM becomes important. Principals forming modes of PCM are bending and drawing. Paint films are PCM are mainly subjected to tensile strain in bending, and to both tensile and compressive strain in deep drawing [2].

Coil coating is increasingly use in different fields but can be divided into the following markets: construction, household electrical goods, transport, packaging and metal furniture and many more [2].

The polyester paint widely applied coatings with good flexibility and suitable for continuous exposure at temperature up to 120 °C. Various formulations are available that offer good deep drawing properties, resistant to chemical attack and that are suitable for exterior use. Typical applications are consumer durable, deep drawn components and building component [3]. PVC Plastisol paint has a plasticizer-bearing coating with very good flexibility. Can be drawn and formed easily. Suitable for embossing for decorative purposes and can be used in internal and external applications. Typical applications are roofing and cladding on buildings, curtain walling, furniture, vehicle fascia panels, garage doors [3]. Jerzy *et al.* (1990) investigated effect of deformation on the damage to the three different coatings, Polyethylene, Acrylic, and PVC, of sheet steels in line and complex strain path. They had been found that the cracking limit curve and the flaking limit curves are influenced by the strain path [4]. In other study theses researchers investigated analysis of the limit strains of coated sheet steel for different strain path. As a result of the investigation performed, it was ascertained that the forming limit curves, their position and their shape obtained for different strain paths, depend on the kind of coating [5]. Mitter *et al.* (1997) investigated a comparative study on the evolution of the tribological behavior polymer / zinc coated steel sheets. They had been shown that a major factor affecting the formability of coated automotive steel sheets is the interfacial frictional behaviour between the sheet and the forming die [6].

Masaaki Yamashita *et al.* (2000) investigated effect of two coated layer on the 55%Al-Zn alloy coated steel sheet. They show that increasing of thickness coated layer due to improvement formability of steel sheet [7].

Vander AA *et al.* (2000) investigated an experimental and numerical study of the wall ironing process of polymer coated sheet metal. In this study, the application of a polymer coating on both sides of the metal sheet has been investigated; both for polymer coated aluminum and for polymer coated steel [8].

Carlson *et al.* (2001) investigated tribological performance of thin organic permanent coatings deposited on 55%Al-Zn coated steel. The results obtain show that the tribological properties of thin organic permanent coatings are strongly influenced by the coating thickness [9]. In this year these researchers investigated friction and wear mechanisms of thin organic permanent coatings deposited on hot-dip coated steel. They understand that these coatings have the potential to increase the formability without additional lubrication and serve as temporary corrosion protection during transportation [10].

Kohei Ueda *et al.* (2001) investigated the effect of mechanical properties of paint film on the forming of pre-painted steel sheet. In this study, they had been obtained elongation, tensile strength, and elastic strain energy of free paint films and the friction coefficient of PCM [11]. In this year these researcher investigated visco-elastic properties of paint films and formability in deep drawing of pre-painted steel sheets [12]. In 2002, they investigated formability of polyester/melamine pre-painted steel sheet from rheological aspect. In 2003, they investigated development of chromate-free pre-painted steel sheet having high corrosion resistance [13]. Zhrang Wang et al. (2003) investigated FEM (finite element method) analysis of contact mechanism in press forming of lubricant pre-coated steel sheet [14]

Bastos *et al.* (2004) investigated formability of organic coatings with electromechanical approach. In this study, coil-coated samples of electrogalvanized steel were submitted to uniaxial, biaxial and plane strain of various magnitudes and tested by electromechanical impedance spectroscopy (EIS). They understand that a good correlation was encountered between the coating resistance and the equivalent plastic strain [15].

MATERIAL AND METHODS

Sample specimens

Hot-dip galvanized steel sheet(0.5mm in thickness) having a zinc layer on both sides(0.01mm in thickness) and chromate treated(zinc molten bath at temperature 450–460 °C), was coated with polyester and plastisol paint. For investigation and comparison of formability properties of pre-painted steel sheet, we prepared three series of specimens.

First series, specimens were coated with polyester paint with constant thickness of primer-coat ,Beckryprim 207, wet film 15 μm and dry film 5 μm, and different thickness of polyester top-coat, Beckrypol 340, 30, 38, 44, 60 μm. after baking in furnace, these thickness of top-coat were 10, 13, 15, 19.5 μm, respectively. The primer and top-coat baked at the peak metal temperature (PMT) of 230-240 °C for 30s.

Second series, specimens were coated with constant thickness of primer-coat of acrylic paint ,Beckrypol E220, wet film 38 μm and dry film 15.5 μm, and different thickness of plastisol top-coat, Beckryplast FJ240, 100, 150, 200, 300 μm. after baking in furnace, these thickness of top-coat were 62, 106, 148, 200 μm, respectively. The primer and top-coat baked at the peak metal temperature (PMT) of 230 and 205 °C, respectively, for 30s. 3rd series, specimens were coated with constant thickness of top-coat of plastisol paint , Beckryplast FJ240, wet film 200 μm and dry film 148 μm, and different thickness of acrylic primer-coat, Beckrypol E220, 30, 38, 44, 60 μm. after baking in furnace, these thickness of primer-coat were 13.2, 15.5, 17.2, 22 μm, respectively. The primer and top-coat baked at the peak metal temperature (PMT) of 230 and 205 °C, respectively, for 30s.

The length of these specimens was 115 mm and the width of those was 25, 38, 50, 63, 76, 88, 115 mm, respectively. These paints were painted by bar-coater. Table1 shows Chemical composition of steel sheet (ST14) that used in this study.

Table 1 Chemical composition of steel sheet

%C	*%Si*	*%Mn*	*%P*	*%S*	*%Cu*	*%Al*	*%N(ppm)*
0.035	0.004	0.223	0.006	0.004	0.027	0.057	41

Test methods

Forming limit diagram (FLD)

The rectangular drawing test of PCM, as shown in **Fig. 2**, was performed. The size of punch is 60 mm × 60 mm. The maximum blank hold force was 12000 N, and the speed of the punch was 0.4 mm/s, and the maximum displacement of punch is 80 mm. this test was performed at 25 °C.

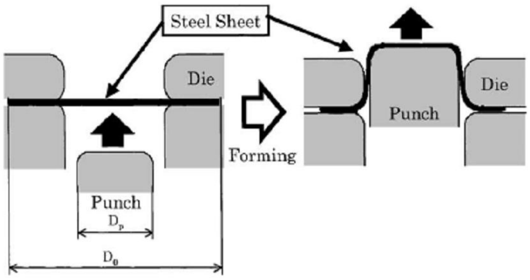

Fig. 2 Procedure of deep drawing test, D_0 diameter of blanked steel sheet; D_p diameter of punch

In this method, the experimental procedure mainly involves three stage- grids marking the sheet samples, punch stretching the grid marked samples to failure or onset of localized necking and measurement of strain with miller ruler (Fig. 3).

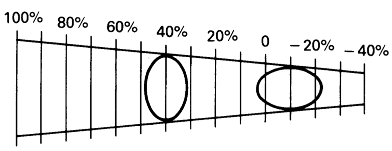

Fig. 3 Schematic of miller ruler

The fractured specimens after deep drawing test are shown in Fig. 4.

Fig. 4 Deep drown samples of painted galvanized steel sheet

RESULT AND DISCUSSION

Forming limit diagrams

The forming limit diagram of sheets was obtained by deep drawing experiments on specimens have different width as describe earlier. Because of the large scatter in the measured strains with varying blank width and also due to the overlap of some point (the maximum safe strains and the strain in the portions where necking has just started), it is difficult to draw a very prices curve that indicate the onset of failure [16].

The following points have been observed:

1. Coatings have the potential to increase the formability without additional lubrication and serve as temporary corrosion protection during transportation [11]. The paint films having higher maximum strain had better formability in drawing [10]. The paint films which exhibit high plasticity in a large deformation process, have good formability in deep-drawing [13]. The forming limit curves, their position and their shape obtained for different path, depend on the kind of coating. The improvement of the formability steel sheet depends on the coefficient of friction between the tools and steel sheet [4].

The limit strains of uncoated galvanized steel sheet are lower when compared to coated galvanized steel sheet (Fig. 5**)**. The difference could be due to the presence of a paint layer between the galvanized steel sheet and punch. This layer acts as a lubricant and due to the decrease of coefficient friction of between the galvanized steel sheet and punch. This decrease in coefficient friction of between the galvanized steel sheet and punch, result better formability of galvanized steel sheet [4, 5]. In experimentally evaluated (FLD) of the coated galvanized steel sheet with thickness of polyester topcoat 19.5 μm, the limiting strains are fairly high, the highest major strain being close to 50% compared to other coated galvanized steel sheets (46-48%). For the plane strain condition (e_2=0) in coated galvanized steel sheet with thickness of topcoat 19.5 μm, the maximum safe major strain was about 19-20% compared to other coated galvanized steel sheets with polyester paint (17-18%). The area below the line is the safe working zone for the sheets for all possible combination of strains. Above the line, the sheet metal is certain to fail by necking/fracture. The area on the line represents the critical region where the sheet is likely to develop the necking/onset of failure.

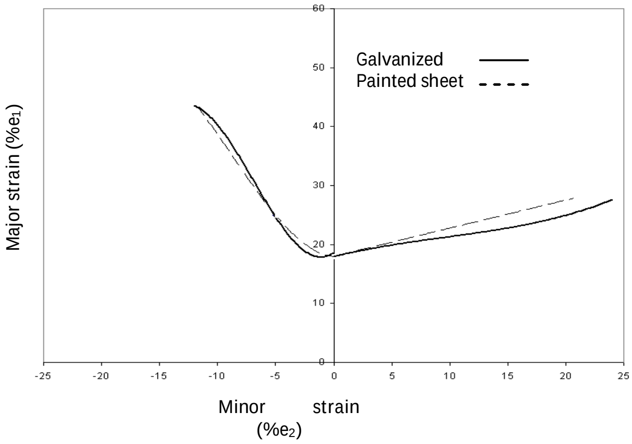

Fig. 5 Comparison of the forming limit diagrams of uncoated galvanized steel sheet and coated galvanized steel sheet Fig. 6 shows the comparison of forming limit diagrams for galvanized steel sheets that coated with different thickness of polyester top-coat and constant thickness of polyester primer-coat.

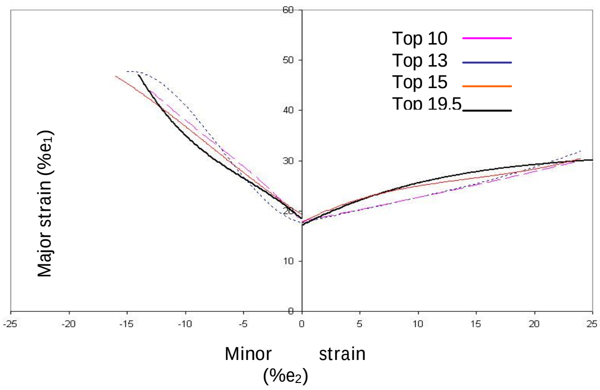

Fig. 6 Comparison of the forming limit diagrams of galvanized steel sheet that coated with different thickness of top-coat and constant primer-coat (5 μm in thickness) of polyester paint

2. The difference in maximum safe strains of four coated galvanized steel sheets indicates the effect of coating thickness on formability. It is observed that as the coating thickness increased, the limit strains have increased [16].
3. In left-hand side of the curve, because of large scatter in the measured strains with varying blank width and due to overlap of the points, the difference of limit strains of coated galvanized steel sheet are not very clear from the forming limit diagrams [16].
4. In left-hand side of FLDs that possesses low values of e_2/e_1 there are not clarity differences between values of measured limit strains. Therefore, in this region, it can be neglected the effect of paint film thickness on the formability of galvanized steel sheet [16].

5. Fig.7 shows the comparison of forming limit diagrams for galvanized steel sheets that coated with different thickness of plastisol top-coat and constant thickness of acrylic primer-coat (15.5 μm in thickness). It is observed that with increasing of thickness of top-coat, galvanized steel sheet had a higher limit strains and formability could be better.

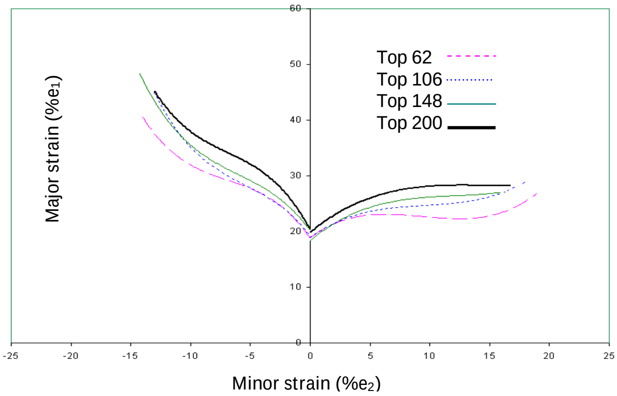

Fig. 7 Comparison of the forming limit diagrams of galvanized steel sheet that coated with different thickness of plastisol top-coat and constant acrylic primer-coat (15.5 μm in thickness)

6. Fig.8 shows the comparison of forming limit diagrams for galvanized steel sheets that coated with different thickness of acrylic primer-coat and constant thickness of plastisol primer-coat (148 μm in thickness). It is observed that with increasing of thickness of primer-coat, galvanized steel sheet had a higher limit strains and formability could be better. In this FLD curve, in positions with low values of e_2/e_1, there are not clarity differences between values of measured limit strains.

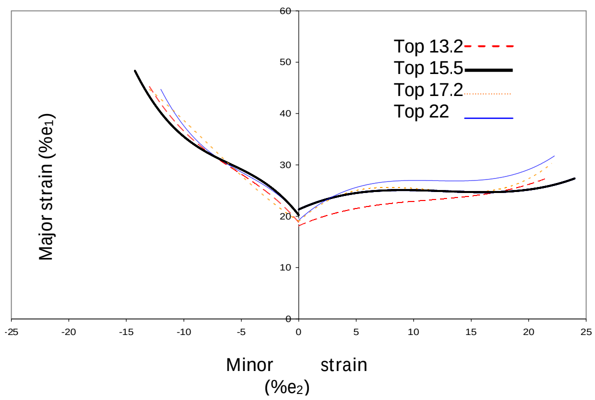

Fig. 8 Comparison of the forming limit diagrams of galvanized steel sheet that coated with different thickness of acrylic primer-coat and constant plastisol top-coat (148 μm in thickness)

7. The best FLD (best formability) for galvanized steel sheet that coated with polyester and plastisol paint compared in **Fig. 9**. Due to presence of PVC particle in plastisol paint, galvanized steel sheet that coated with plastisol paint have better formability than polyester paint.

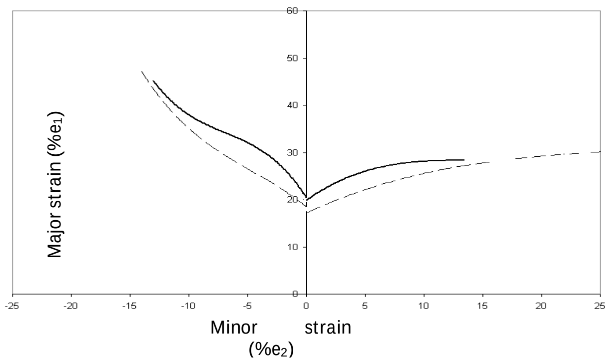

Fig.9 Comparison between best FLD of galvanized steel that coated polyester and plastisol paint

CONCLUSIONS

The following conclusions are drawn from previous sections:

1. For complex strain paths, the effect of the coating on the FLDs increases with increasing value of e_2/e_1 in the last step of deformation.
2. The limit strains of the uncoated galvanized steel sheet are lower than those of coated galvanized steel sheet.
3. As the coating thickness increased, the limit strains have increased. The limiting strains of galvanized steel sheet coated with polyester topcoat 19.5 μm is higher when compared to other galvanized steel sheet coated with polyester topcoat with lower coating thickness in both plane strain and biaxial stretching.
4. The paint film that located between punch and sheet decreased the value of coefficient of friction at the punch- sheet interface. Therefore, with increasing thickness of paint film, the value of coefficient of friction at the punch-sheet interface has been decreased and with formability of paint sheet has been improved.
5. Because of the presence PVC particle in plastisol paint, galvanized steel sheet that coated with plastisol paint have better formability than polyester paint.

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