Zinc Coating

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Advanced high strength galvanized steel sheet has been one of the dominant materials of modern automotive panels because of its outstanding mechanical properties and corrosion resistance. The zinc coating thickness of hot dip galvanized steel sheet is only about 10–20μm, which is a discarded object on the macro level. However, it is obvious to damage and impact on stamping performance. Therefore, this work takes zinc coating as the research object and builds its mechanical constitutive model based on a nano-indentation test and dimensional analysis theory. We separated the zinc coating from the galvanized steel substrate and constructed a sandwich material model by introducing a cohesive layer to connect the zinc coating and the steel substrate. We obtained the interface binding energy between the zinc coating and the steel substrate through the nano-scratch test. The accuracy of the model is verified by the finite element analysis of hemispherical parts. We used the five-layers element model with 0 thickness cohesive layer to simulate the zinc coating damage of galvanized steel sheet. The hemispherical part drawing experiment is used to verify the feasibility of the finite element analysis results. The results demonstrate that it is more accurate to consider the finite element numerical simulation of the zinc coating, introducing the cohesive element to simulate damage between the coating and the substrate. Drawing depth, stamping force, and the strain of the numerical simulation are closer to the experimental results.

Keywords: hot dip galvanized steel sheet ; zinc coating ; mechanical behavior ; damage ; cohesive element

1. Introduction

Galvanized advanced high strength steel (AHSS) has become the dominant material of automotive lightweight because of its superior strength, elongation, and outstanding corrosion resistance, which can follow the requirements of collision safety, energy saving, emission reduction, and environmental protection[1]. The coating is an ultra-thin material galvanized on the upper and lower surfaces of the steel substrate. There are two galvanizing methods: hot-dip galvanizing and electro galvanizing [2]. The thickness of the zinc coating is about 8 μm [3], which represents a slight difference between galvanizing methods. It neglects this level of magnitude on macroscopic scales. But zinc coating layer makes the surface characteristics of galvanized steel different from that of non-galvanized steel. These zinc coating layers are easy to damage in severe plastic deformation under external pressure and sliding friction [4][5][6]. It will also affect the formation of welding joints of stamping parts [7]. Typical damages of the coating layers are cracking and powdering flaking. The exfoliated coating adheres to the surfaces of the steel and die, resulting in falling, wearing, and affecting the stamping formability of the steel sheet [8][9]. Therefore, it is of great practical significance to study the mechanical properties of the zinc coating and its influence on the deformation of galvanized AHSS during stamping forming.

2. Specifics

Zinc plating is an alloying process, and its element content will influence the performance of the galvanized layer. Vourlias et al. [10] studied the effect of alloying elements on the interfacial reaction of the galvanized coating. They found that the concentration and distribution of alloying elements played an important role in the phase growth. To improve the coating quality of high strength DP steel, a nickel layer was pre-electroplated on the steel substrate before galvanizing, and an enhancement in the coating quality was discovered [11]. Parisot et al.[12] confirmed the damage mechanisms at work in three different microstructures of a zinc coating on an interstitial-free steel substrate under tension, plain strain, and expansion loading. Two main fracture mechanisms, intergranular fracture and transgranular boundary fracture, were created in cold-rolled coatings, tempered cold-rolled coatings, and uncrystallized coatings. Further investigation shows that the damage between the galvanized layer and substrate depends on the different mechanical behavior and thickness of intermetallic compounds [13]. Petit et al. [14] investigated the galvanization ability of a high strength chromium-rich TRIP800 (transformation induced plasticity steel). Under different loads and deformation conditions, zinc coating also shows different mechanics. The damage behavior of different galvanized steel sheets under tension-bending conditions was explored by Yu et al. [15]. They discovered that the exfoliating and scratching of coating are two types of surface damage. To quantify the damage of galvanized coating, Xu et al. [16] suggested a parameter to illustrate the powdering of galvanized coating and its validity by double reverse Olsen test. Song and Sloof [17] introduced a “macroscopic atomic model” to assess the adhesion of the zinc coating for hot-dip galvanized dual phase steel. Adhesion force is an important property of coated steel, which concluded the quality of the coating. The damage of the coating in the stamping process results from the relative sliding friction between the steel sheet and the die surfaces. Wang et al. [9] considered the evolutionary process of galling of galvanized AHSS DP590 (dual-phase steel) under the condition of friction coupling plastic bending deformation. First, the coating is cracked because of tensile deformation. Then, further powdering of the coating resulted in a notable increase in the surface roughness of the contact interface. Die wear and surface galling of stamping parts will be caused because of the adhesion effect of coating. Therefore, the coating layer must be considered as an essential research branch of AHSS stamping.

Numerical simulation is an effective tool and method to study the strain distribution stamping forming [18]. As a non-negligible factor, we must consider the coating in the numerical simulation of stamping forming. The upper and lower surface of the galvanized steel sheet is zinc coating, and the intermediate substrate is a steel sheet. We can understand it as three-layers of composite material, like a sandwich equivalent to the stamping of multiple layers of material. It includes multi-scale modeling of materials [19], stamping formability [20][21][22], spring-back[23][24], and evolution of interface structure [25]. A three-dimensional finite element (FE) simulation of a thin zinc coating on a galvanized steel sheet has been performed by taking the multicrystalline structure of the coating into account [26]. In addition, Ucun and Aslantas [27] simulated the mechanical properties and force status of the cutting tools with different coating types by the method of single layer and multi-layer finite element modeling. Lee et al. [28] simulated the deep drawing of galvanized steel with a multi-layer element model, and the interface between substrate and coating was set to be adherent. Kim et al. [29] studied the fracture of the coating layer of galvanized steel using V-bending test and numerical simulation of the solid element. The results show that the coating and substrate begin to failure when the local plastic equivalent plastic reaches 0.26–0.28. Bettaieb et al. [30] proposed a solid shell element to describe the coating under T-bending based on the enhanced assumed strain (EAS) technique and the assumed natural strain (ANS) technique, that can avoid locking problems caused by the large aspect ratio of ultra-thin coating elements. It is shown that a higher accuracy simulation of coating can be achieved by using such a solid shell element.

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