Chapter 7
Tribological Behaviour of Plasma-Nitrided Die Steels

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ABSTRACT

Wear, plastic deformation, and mechanical fatigue of dies are the most common failures found during hot forming operations at elevated temperatures. The change in frictional behaviour also happens. The performance of the forming operation is affected. To ensure the quality of the end products and productivity, it has become very important to control the wear and friction of die materials. Surface treatment techniques with superior wear properties and good performance can enhance the life and functionality of dies. Plasma nitriding is the most rapidly developing technique for hot forming dies. It is a cost-effective technique and improves the mechanical properties of the die surfaces. This chapter explains the tribology of hot forming dies, the plasma nitriding technique, and the procedures to develop plasma nitriding on the die steels. Thereafter, the tribological behaviour of AISI H11 and AISI H13 plasma nitrided die steels has been reported. Plasma nitriding was found to be most promising and effective in reducing wear and friction at elevated temperatures.

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INTRODUCTION TO TRIBOLOGY

Tribology, or the study of friction, wear and lubrication, is the branch of science that deals with the study of interacting surfaces in relative motion (Hutchings, 1992). It is a complex science with theoretical calculations of few possibilities of wear and friction in the materials in contact and sensitivity of the system to operating conditions and environment. A tribological system consists of four main elements that control the overall behaviour. The first two elements are the materials of the surfaces close to each other. The third element is the interfacial medium, which can be a lubricant such as oil, gas or another form of an intermediate layer. Finally, the fourth element is the surrounding environment which is usually the surrounding air (of varying humidity), other gases, fluids or even a vacuum in the case of mechanisms utilized in space. All these elements together determine the friction and wear characteristics of the particular system. In other words, friction and wear properties are not intrinsic or inherent properties of the material but are highly dependent on the tribological system (Hardell et al., 2007; Kumar et al., 2017).

Friction is "*the resistance against sliding between two contacting bodies*" (Hardell et al., 2007). In the metal forming process, the existence of friction is necessary. It exists in terms of reaction force. In practice, it is the force that opposes motion between two contacting surfaces. Thus, friction is a part of the energy dissipative process. Sliding friction occurs mainly through contributions from two components, namely the adhesion component and ploughing component. Adhesive friction originates when atomic junctions form between the two surfaces in contact. The higher affinity of the materials will result in increased friction, for example, two steel surfaces in dry sliding will form atomic bonds if the oxide layer on the surfaces is ruptured. Ploughing friction occurs when one of the surfaces is harder than the mating surface, and the asperities of the harder one plough through the softer surface. It may also be caused due to the ploughing action of entrapped hard particles between the bodies. Johnson (2003) mentioned the relation of friction coefficient (μ) by the law of friction as (equation 1):

$$\mu = \frac{F_T}{F_N} \tag{1}$$

The friction coefficient is further divided into two parts, that is, adhesive coefficient (μ_a) and ploughing coefficient (μ_p) as shown in equation 2.

$$\mu = \mu_a + \mu_b \tag{2}$$

The μ_a represents the part of the surfaces which are in contact with each other. The function of μ_a is to control adhesive force between the surfaces in contact. During sliding, the inter surface bonds are formed between the contacting surfaces and are further broken by the adhesive forces. The adhesive force is required, and its magnitude depends upon the surface roughness of the contacting bodies. The μ_p represents the deformation force that results in the ploughing of the weakest part of the surface sliding against the hard surface. It may also be caused due to the ploughing action of entrapped hard particles between the two surfaces in relative motion (Hutchings, 1992; Johnson, 2003; Jacobson and Hogmark, 2005).

Wear is "*a loss of material from the surface*" (Hardell et al., 2007). It is a system parameter that arises when two surfaces are in contact with one another. Wear occurs due to the friction force. The