



# Interface adhesion during sliding wear in cast iron after hot deformation



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## ABSTRACT

Interface adhesion between cast iron substrate and oxide layer formed during dry unidirectional sliding wear was studied by using thermo-mechanically processed 4.8Ni–1.5Cr cast iron. The purpose of the present work is to reveal the difference of the adhesion behaviour between martensitic matrix with a higher hardness and austenitic matrix with low hardness. The 4.8Ni–1.5Cr alloy was sandwiched as a middle layer with low carbon steel as outer layers and thermo-mechanically processed via (1) hot rolling (HR), (2) hot rolling and heat treatment (HT), and (3) hot rolling, heat treatment and hot compression (HC), respectively. The applied normal loads were 20 and 40 N, and the sliding speeds were 45 and 78 mm/s in sliding wear test. The durations of the wear test were 2 and 7 min, respectively for different testing rounds. It was found that the wear after running-in was always mild under the conditions of 20 N and 45 mm/s or 20 N and 78 mm/s for all the tested samples. Prior to the transition into mild oxidational wear, negative displacements of pins were observed for HT and HC samples when the applied load was raised to 40 N at the sliding speed of 78 mm/s. No similar response was observed for HR sample under the same testing condition. The possible mechanisms for the negative displacement of pin in the test are discussed in terms of the microstructure and phases of the testing samples. The effect of the hardness of the substrate on the growth and integrity of the oxide film formed during the sliding and the interface adhesion between the oxide film and substrate are also discussed.

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## 1. Introduction

Cr-bearing cast iron is traditionally treated as a material that has an excellent wear resistance [1]. However, its inferior formability greatly limits its wide use in service [1,2]. One of the effective ways to substantially enhance the formability of cast iron and therefore broaden its superiority in resistance to wear is to refine coarse eutectic carbides in matrix by using spraying forming method [2–5]. An alternative reported recently by Xie et al. is to have a sandwich structured bimetal consisting of a high chromium cast iron core and low carbon steel outer protective layers [6]. In the sandwich composite, the cast iron can be significantly deformed by hot rolling. As the shaping performance or formability of cast iron can be improved in this way, it will become feasible to investigate the wear performance of cast iron under various deformation conditions.

Oxidational wear may occur when oxygen is involved in conditions in which two metal surfaces are sliding against each other. In 1930, Fink published the first paper concerning this phenomenon, implying that oxidational wear had become a

family member of the wear of metals, as mentioned in an extensively cited review published by Quinn [7]. Since then, a wide range of investigations have focused on the nature of this wear. Oxidational wear is traditionally accepted as a wear regime where protective films are built up on the contacting surfaces of metals. As oxidational wear involves the chemical reaction of metal surfaces with oxygen, compared with pure physical sliding between two metals, the wear is mild [7]. Once the protective layers are effectively and stably formed, the sliding pair can be prevented from metal-to-metal contact, and therefore the wear loss will be lowered [7,8].

As oxide-to-metal or oxide-to-oxide contact dominates the whole process of sliding, the formation of such a lubricating film has always been the foremost concern for researchers. Stott in 1978 [9] proposed that a considerable amount of oxide debris is produced at the beginning when two metal components sliding against each other and some of the debris created is retained between the contacting surfaces. After further sliding contact, these products can become highly compacted locally. Similar events of transient growth are subsequently removed and more products are produced in the same way during sliding until sufficient wear debris becomes confined, then an oxide layer is formed. However, from the perspective of diffusion, Quinn [7] argued that oxidation occurs by diffusion of oxygen ions inwards and (sometimes) by metal ions outwards. The plateaux that originally

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existed or were produced after initial metal-to-metal contact on the rubbing surfaces are primarily thickened at the interface between the oxide and the metal beneath the asperity contacts. A number of thoughts, originated from the above two views regarding the formation of this lubricating layer developed and prevailed over the following years, proposed in [10–12] which were consistent with the former and the latter [13].

In terms of the mechanisms of oxidational wear, researchers have put great efforts into studying the ways of the mass loss of sliding pairs. The mass loss really depends on how the protective tribo-oxide film is formed and maintained, and therefore, many wear models have been proposed. Quinn firstly speculated in 1967 that the wear rate totally attributes to the oxidation rate [14]. Since then, other mechanisms were proposed and each one of them was likely to be applicable to a certain given tribo-system because the parameters are usually different, especially the load, sliding speed and the real contact temperature, either externally provided or internally stimulated by sliding [15]. Wilson and co-workers in 1980 [16] suggested that the removal of this protective oxide layer relates to poor adhesion between asperity surfaces involved in sliding contact, and subsequently the oxide layer fails to bond at oxide-substrate interface or within the oxide layer. Quinn in 1983 [7] maintained that a fatigue mechanism which mainly causes loss of materials could be operating when the oxide layer reaches its critical thickness, due to fatigue cracks distributed regularly at right angles to the direction of sliding. Subsequently, Quinn in 1984 [17] suggested that competition between the shearing and tearing, and the self-healing properties of oxide films on wear surfaces may be operating during mild wear.

However, there are still controversies over the interface adherence between the protective oxide layer and substrate, and the maintenance of such a highly wear resistant film. Some researchers believed that a good match between the metallic and oxide interfaces is mainly responsible for the formation and maintenance of the lubricating film [11,18–21], while others advised that it would not be an effective supporter for building up such a layer when the substrate becomes relatively soft [22,23]. Stott and Jordan [24] believed that a high chrome steel substrate with a low hardness can act as a good upholder for establishing an oxide film. They found that deeper grooves could

be developed especially in the early stages of wearing, and the grooves would provide convenience for accumulating and retaining the loose of wear debris locally.

In view of this, the sliding wear response of 4.8Ni–1.5Cr cast iron with martensitic and retained austenitic matrices was studied in this work to further explore the adhesion behaviour at the oxide-substrate interface. Chromium-bearing cast iron is often considered as an excellent candidate material where the high wear resistance is pursued. Proper content of chromium could also facilitate the formation of a stable and healthy protective tribo-layer. The oxidational wear behaviour in non-lubricated sliding wear of cast iron, which was obtained via bimetal forming and subsequent hot deformation using Gleeble 3500, is investigated for the first time.

## 2. Experimental

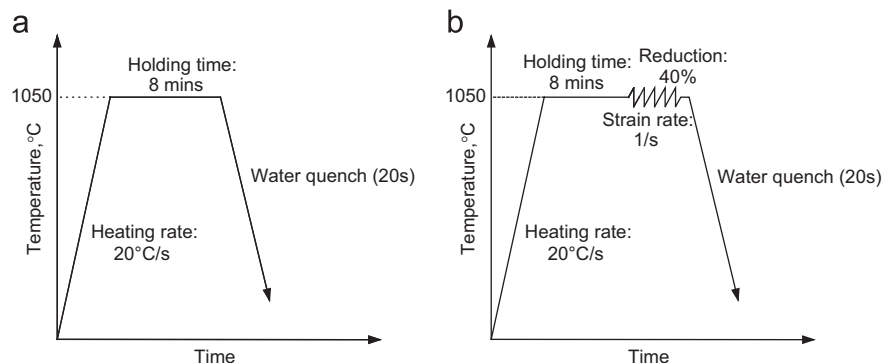
### 2.1. Sample preparation

The alloy used in this wear test was a cast iron as middle layers, fabricated with low carbon steel (LCS) as outer layers. The LCS contains 0.15–0.20% (wt%), and the composition of cast iron used in this study is listed in Table 1. The sandwich structured composite was obtained by hot rolling after LCS and cast iron were casted together. Details on the method of fabrication of this type of composite may be found elsewhere [6]. The hot rolling temperature was around 1050 °C. During hot rolling, the LCS can perform as protective layers covering the cast iron as the core layer, due to the excellent ductility of LCS. If the cast iron layer is being hot compressed without the protection of LCS as outer layers, the deformation process may not be achieved as the cast iron may be very close to semi-solid state at 1050 °C.

After hot rolling process and air cooling to room temperature that leads to a metallurgical bonding at LCS-cast iron interfaces, the composite was wire-cut into cylinders with 12.05 mm in diameter and 14.10 mm in height. The thicknesses of the three layers were almost the same. Two cylinders were then tested using a Gleeble 3500 thermo-mechanical simulator. The Gleeble 3500 is a fully integrated digital closed loop control thermal and mechanical testing system. It can hold a steady state equilibrium

**Table 1**  
Chemical compositions of the cast iron and pin material used in this study (wt%).

	C	Cr	Ni	Mn	Si	Mo	P
Cast iron (Disk)	2.0	1.50	4.80	0.78	0.99	0.27	0.02
AISI E52100 (Pin)	0.98–1.10	1.30–1.60	–	0.25–0.45	0.15–0.30	< =0.025	< =0.025



**Fig. 1.** Thermal cycles for the sample to be heat treated (a) and the sample to be hot compressed (b).

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