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Interface Analysis and Hot Deformation Behaviour of a Novel Laminated Composite with High-Cr Cast Iron and Low Carbon Steel Prepared by Hot Compression Bonding

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Abstract: A hot compression bonding process was developed to prepare a novel laminated composite consisting of high-Cr cast iron (HCCI) as the inner layer and low carbon steel (LCS) as the outer layers on a Gleeble 3500 thermomechanical simulator at a temperature of 950 ℃ and a strain rate of 0.001 s^{-1}. Interfacial bond quality and hot deformation behaviour of the laminate were studied by microstructural characterisation and mechanical tests. Experimental results show that the metallurgical bond between the constituent metals was achieved under the proposed bonding conditions without discernible defects and the formation of interlayer or intermetallic layer along the interface. The interfacial bond quality is excellent since no deterioration occurred around the interface which was deformed by Vickers indentation and compression test at room temperature with parallel loading to the interface. After well cladding by the LCS, the brittle HCCI can be severely deformed (about 57% of reduction) at high temperature with crack-free. This significant improvement should be attributed to the decrease of crack sensitivity due to stress relief by soft claddings and enhanced flow property of the HCCI by simultaneous deformation with the LCS.

Key words: bonding; laminated metal composite; interface structure; hot working; high-Cr cast iron

Laminated metal composites (LMCs) have drawn considerable research attention over the past two decades due to their unique properties including advanced mechanical performance and virtuous complementarity between constituent metals[1-16]. Fabrication of materials in the form of laminated structure with immaculate interfacial bond can significantly improve many properties such as fracture toughness, impact resistance, fatigue behaviour and damping capacity, or provide enhanced ductility or formability for otherwise brittle materials[1,2]. Based on the advantages, increasing efforts have been focused on improving the workability of the brittle metal or alloy by means of lamination with the ductile material[5,6].

It is well known that high-Cr cast irons (HCCIs) possess high hardness and excellent wear resistance with inherent severe brittleness because of the microstructural characteristics consisting of massive hard carbides in ferrous matrix[17-19]. High crack sensitivity derived from the brittleness results in an inferior deformability of the HCCIs. Hence, the shaping of them is usually carried out by casting technology or spray forming in liquid state. Although some investigations have concentrated on the development of the laminated components with HCCI and low carbon steel (LCS) or medium carbon steel (MCS) prepared by cast or diffusion bonding[4,15,16,20-22] to improve their impact resistance, the workability of the brittle HCCI with ductile metallic lamination has not been discussed till now. It is worth mentioning that the laminated components such as bimetal hammer,

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composite liner and cladding roller have been used in applications which require excellent wear resistance and sufficient toughness.

Compared with the cast and diffusion bonding, hot compression bonding such as rolling and forging processes is more effective and efficient. It can not only produce large scale LMCs at a lower cost with higher productivity, but also improve the mechanical properties of the constituent metals and synthetic performance of the composite by refining the microstructure or developing the preferred macro/micro texture during plastic deformation. In this study, a hot compression bonding process was explored to fabricate a novel sandwich structural LCS/HCCI/LCS laminate. Interfacial bond quality was analysed by microstructural observations and mechanical tests. The hot deformation behaviour of the HCCI with and without lamination was compared to elucidate its workability.

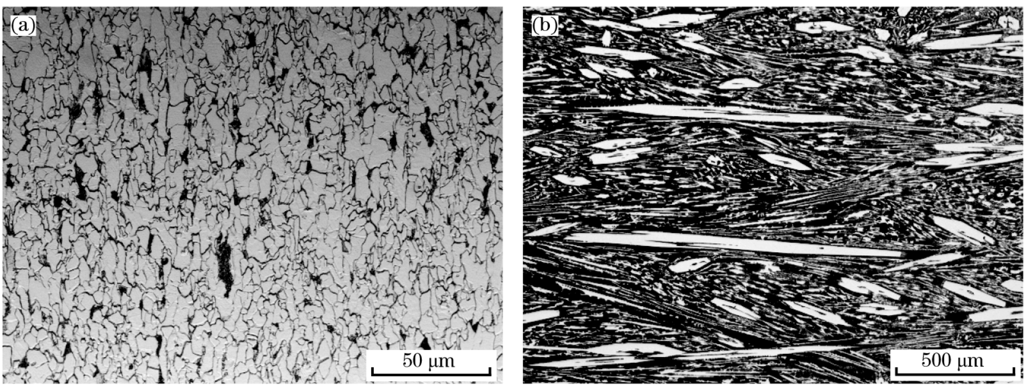
1 Material and Experimental Procedure

1.1 Material

The chemical composition and Vickers hardness of the raw materials are listed in Table 1, in which the HCCI (in as-cast state) is characterised by high hardness and stiffness, whereas the LCS (in hot-rolled state) with low hardness implies excellent toughness and ductility. Masahashi et al.[5,6] reported that simultaneous deformation together with soft material is a beneficial method for deforming hard material by stress relief, even though the plastic instabilities in one of the components happen earlier than the other one due to prominent differences in mechanical properties[23]. Figs. 1(a) and 1(b) show the initial microstructures of the LCS and the HCCI, respectively. It can be seen from Fig. 1(a) that the LCS consists of high volume fraction of ferritic structure with fine grain size and a small quantity of pearlitic patches located at trilateral positions. This microstructure will transform to fully austenite at high temperature, and then impart a favourable flow ability to the LCS. On the other hand, Fig. 1(b) presents the typical microstructure of the HCCI by the presence of large hexagonal primary M_7C_3 carbides and interdendritic eutectic M_7C_3 carbides in a matrix of martensite with retained austenite. These hard carbides contribute to outstanding wear resistance, but meanwhile severely deteriorate the workability of the HCCI.

Table 1 Chemical composition (mass%) and Vickers hardness (HV) of HCCI and LCS

Material	C	Si	Mn	P	S	Cr	Ni	Mo	Hardness
HCCI	2.4	1.20	0.90	0.020	0.030	23.00	0.3	0.5	868±50
LCS	0.1	0.15	1.61	0.014	0.002	0.21	—	—	176±3



(a) LCS; (b) HCCI.

Fig. 1 Initial microstructures of constituent metals of laminated composite

1.2 Hot compression bonding test

In order to simulate hot roll or forge bonding processes, a Gleeble 3500 thermomechanical simulator was employed to carry out laminated bonding test. It is recognized that the Gleeble is a dynamic testing machine which can simulate a wide variety of thermal-mechanical metallurgical situations[24]. According to the requirement of the simulator, the specimens of HCCI and LCS were cut into cylinders with dimensions of ϕ10 mm×6 mm and ϕ10 mm×3 mm, respectively.

Prior to bonding test, all the contact surfaces were