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Preparation and High Temperature Tensile Mechanical Properties of Multilayer Metal Hot Forging Die Specimens

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Abstract. The bonding strength of cladding is the key to the normal use of multilayer metal hot forging die. This paper presents a method of multilayer metal specimens prepared by PTAW. The specimens are selected H13 steel as the substrate, M2 steel as the transition layer, Ni60A alloy as the high temperature cladding, and the high temperature tensile test is performed on the Gleeble 3500 machine. The research results show that the substrate and cladding have good metallurgical bonding and the cladding hardness is higher than the substrate. Compared with H13 specimens, tensile strength of cladding metal specimens increase, elongation and yield strength decrease. All tensile fractures appeared on the H13 substrate during the experiment. It indicates that the cladding strength and bonding strength are higher than the substrate and the high temperature strength of cladding metal hot forging die is overall superior to H13 hot forging die.

Keywords: Multilayer metal hot forging die; PTAW; Gleeble high temperature tensile; Mechanical property; Fracture

1. Introduction

Hot forging die bears cyclic mechanical load during billet deformation process. It will be easily damaged due to high temperature oxidation, wear and thermo-mechanical fatigue [1][2]. Based on the temperature distribution and service requirements of hot forging die, one or more layers of high performance material claddings are formed on the surface of hot forging die, then a special multilayer structure obtained, namely multilayer metal hot forging die (MMHFD) [3][4]. This method can improve high temperature properties of hot forging die, such as wear resistance and impact fatigue resistance, and uses in the field of life extension and repair of hot work dies. Currently gradient structure of hot work die has become a hot spot. Xu [5] used Stellite6+WC powder on SM400B to prepare the welding cladding and FGM cladding respectively by laser cladding technology. They found that the functional gradient cladding has less crack sensitivity. Cong [6] used laser remelted



specimens to conduct tensile tests, and found that laser repair technology of Biomimetic could improve structure property and tensile strength. Soodi [7] tested the mechanical properties of FGM and sandwich structure under different formulations by room temperature tensile test. BERTI [8] conducted thermal fatigue test for H11 steel by hot forging die service environment simulator, and studied the effects of die surface temperature gradient and hot forging process parameters on the thermal fatigue properties of H11.

In order to study the tensile properties of MMHFD specimens and the bonding strength between cladding and substrate, we propose a method of transverse stretch specimen preparation process and conduct transverse stretching experiments of H13 homogeneous, bimetal (H13+Ni60A) and multilayer metal (H13+W6Mo5Cr4V2+Ni60A) specimens by Gleeble 3500 thermal simulation testing machine. Comparing the high temperature mechanical properties of the above three specimens.

2. Materials and experiments

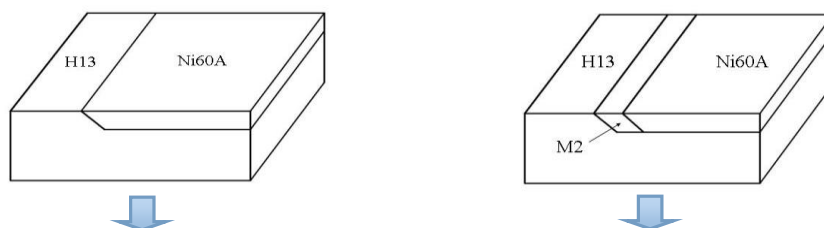
2.1 Material Design of Multilayer Metal Forging Die Specimen

The temperature field of homogeneous hot forging die can be divided into Temperature Fluctuation Zone (600-700 °C), Temperature Equilibrium Zone (400-600 °C) and Cooling Zone (200-400 °C). According to the temperature characteristics, we chose Ni60A alloy for Fluctuation Zone, W6Mo5Cr4V2 (M2) high-speed steel for Equilibrium Zone, and H13 steel for Cooling Zone. We used M2 steel as a transition layer [9]. Table 1 shows the thermophysical properties of three materials [10].

Table 1. Thermophysical properties of three materials

Material	Coefficient of Linear Expansion (10^{-6}K^{-1})	Thermal Conductivity ($\text{W m}^{-1} \text{K}^{-1}$)	Specific Heat Capacity ($\text{J Kg}^{-1} \text{K}^{-1}$)	Elasticity Modulus (GPa)
H13	10.3-12.2	31.2-28.6	506-587	185-190
M2	10.8-11.27	27.1-26.5	—	230-250
Ni60A	13.9-14.4	26.34-25.56	—	180-195

It is very difficult to prepare specimens conforming to national standards by surfacing. This study proposed a new method of preparing tensile specimens of bimetal and multilayer metal (Figure 1). We machined the groove on the H13 substrate before welding, then selected the "S" path on the groove for PTAW. We chose M2 steel as transition layer and Ni60A alloy as surface cladding. Wire cutting specimens referred to the national standard GBT228-2002.



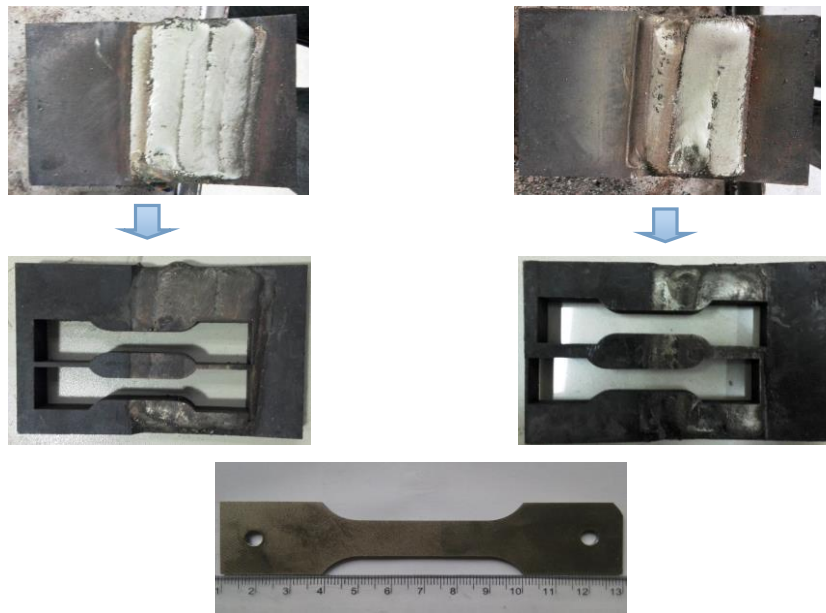


Figure 1. Preparation process of bimetal and multilayer metal tensile specimens

2.2 Experiment in mechanics

Schematic drawings of the high temperature tensile specimens show in Figure 2. J, SH and DH represent homogeneous, bimetal and multilayer metal specimen respectively. Parameters of high temperature tensile test were as follows, the heating temperature were 700 °C, the heating rate was 100 °C s⁻¹, the holding time was 30 s, the deformation rate was 0.02 mm s⁻¹.

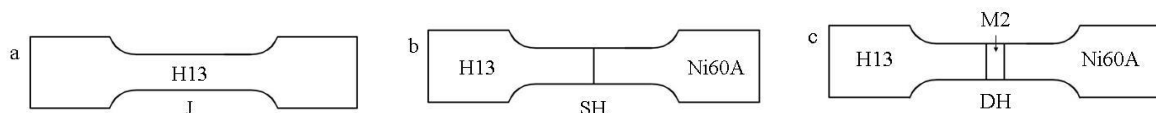


Figure 2. Schematic drawings of the high temperature tensile specimens (a) homogeneous specimen; (b) bimetal specimen; (c) multilayer metal specimen

3. Result and discussions

3.1 Analysis of microstructure and hardness

Figure 3 shows microstructure from H13 substrate to Ni60A cladding (400×). There are globular or blocky perlite and reticulation secondary carbide in substrate (Figure 3a). The heat source of welding makes temperature raise in the zone, leading to the precipitation of secondary cementite and formation of reticulation cementite (Figure 3b). The metallurgical bonding between the fusion interface of the substrate and the transition layer has no obvious cracks or pores (Figure 3c). The transition layer is grown in planar crystal form on the surface of the substrate and then grown in a dendritic form, shows as cast dendrite microstructure (Figure 3d). There is no apparent interface between Ni60A cladding and transition layer, which means it has excellent transition performance (Figure 3e). Ni60A cladding microstructure contains γ -Ni solid solutions, carbides and borides (Figure 3f).

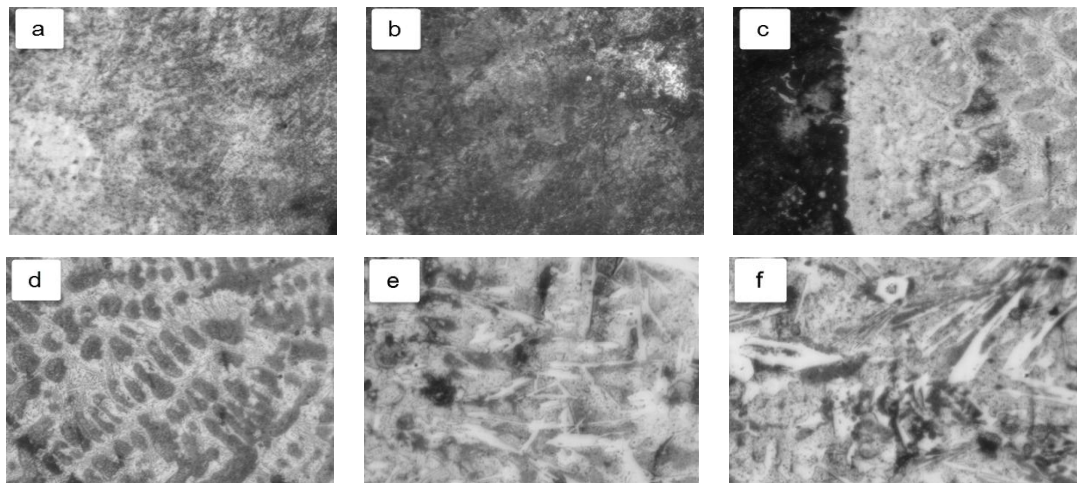


Figure 3. Microstructure from H13 substrate to Ni60A cladding (400 $\times$)

(a) substrate; (b) substrate HAZ; (c) fusion interface between substrate and transition layer; (d) transition layer; (e) fusion interface between transition layer and nickel cladding; (f) nickel cladding

Figure 4 shows the microhardness curves of bimetal and multilayer metal. The microhardness of cladding is higher than substrate. The hardness of bimetal and multilayer metal vary the same on the substrate side. Affected by the quenching of heat source, the hardness of heat affected zone increases to 750HV.

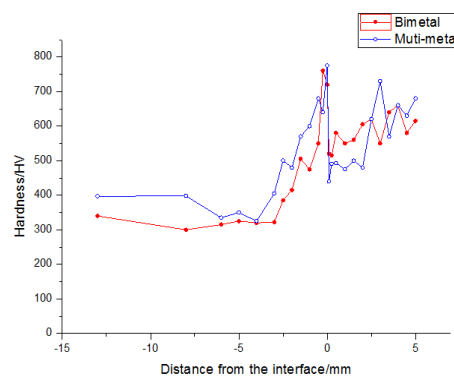


Figure 4. Microhardness curves of bimetal and multilayer metal

3.2 High temperature tensile property

Table 2 shows mechanical performance of high temperature (700 °C) tensile specimens. The plasticity of homogeneous specimen is the best, whose elongation reaches 96.5%. The multilayer specimen reaches 56% and bimetal specimen reaches 44.3%. Elongation of cladding metal specimen is significantly reduced compared with homogeneous specimen; elongation of multilayer metal specimen increases compared with bimetal specimen. The result shows that middle cladding can reduce stress effectively.

Figure 5 shows the high temperature tensile stress-strain curves of specimens. There is no yield point in bimetal tensile curve, no significant plastic deformation before breaking, and no obvious

necking phenomenon (Figure 6b). It indicates that bimetal tensile fracture is brittle. There are two yield points of multilayer metal in tensile process. The reason may be that heat affected zone is reannealed and yielded.

Table 2. Mechanical performance of high temperature (700 °C) tensile specimens

Specimen	Elongation (%)	Yield point(MPa)	tensile strength(MPa)
Homogeneous	96.5	128.3	336.4
Bimetal	44.3	—	409.3
Multilayer metal	56	30.6	348.8
		123.3	

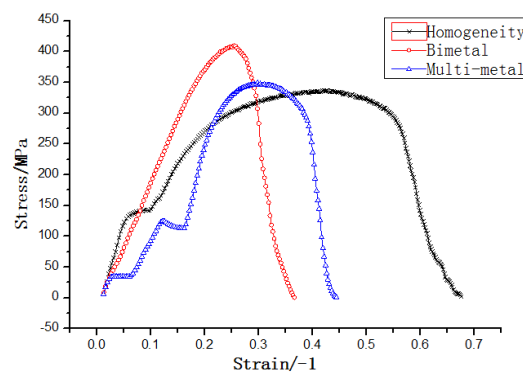


Figure 5. High temperature tensile stress-strain curves of specimens

3.2.1 High temperature stretching fracture analysis

Figure 6 shows the fractures of high temperature tensile specimens. The fracture of homogeneous specimen appears in the center area of specimen, with obvious necking phenomenon and serious oxidation in fracture area (Figure 6a). The fracture appears on the H13 substrate 5-7mm from fusion line, instead of the bimetal specimen center (Figure 6b). The fracture of multilayer metal specimen appears 5mm from the fusion line (Figure 6c).

The fractures appear on H13 substrate instead of cladding. That means the high temperature strength of cladding is better than H13 substrate. The fractures don't appear on fusion area, which means the bonding strength between substrate and cladding and the tensile strength of fusion area is better than H13 substrate.

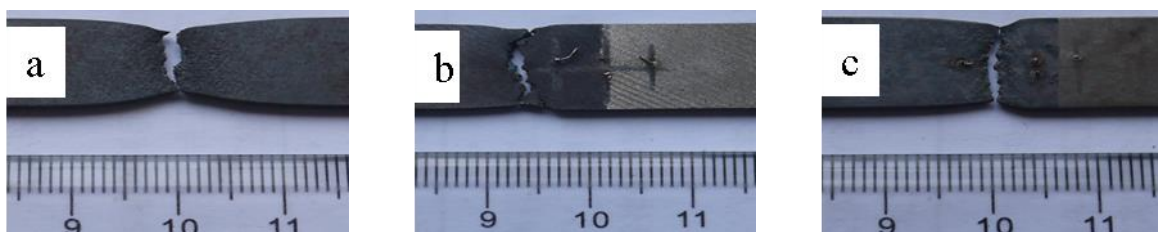


Figure 6. Fractures of high temperature tensile specimens (a) homogeneous specimen; (b) bimetal specimen; (c) multilayer metal specimen

4. Conclusion

- (1) Propose a solution of preparing multilayer metal specimens by PTAW.
- (2) Multilayer metal hot forging specimens prepared by PTAW have good metallurgical bonding between cladding and substrate, and the microhardness of the cladding is higher than substrate.
- (3) Tensile strength of the cladding metal are higher than homogeneous metal, elongation and yield strength decrease during the high temperature tensile test.
- (4) The cladding strength and bonding strength are higher than H13 substrate. High temperature strength of cladding metal forging die is better than H13 hot forging die.

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