BREAKAGE MECHANISM OF TUNGSTEN BASED

ALLOY BLOCK FOR ELECTRO-HEAT UPSETTING[①]

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ABSTRACT

The breakage mechanism of W-Ni-Fe alloy in the process of electro-heat upsetting studied both theoretically and experimetnally, and also the behaviors of crack formation and propagation were analysed. Alloy suffers from corrosion and thermal-mechanical fatigue mutual function. Simultaneously, the practical ways to improve the anvil life was discussed.

Key words: electro-heat upsetting anvil heavy metal thermal-mechanical fatigue corrosion fatigue

1 INTRODUCTION

Heavy alloys are tungsten based metal-matrix composites with little amounts of copper, nickel, iron, cobalt and molybdenum elements. They are classed into two series as W-Ni-Cu and W-Ni-Fe. Due to their advantageous combination of physical properties and mechanical properties, these alloys have found wide applications in many fields, such as counterbalances, gyroscope etc. They also show good perspective to be used both in electric and die- casting industries. Tungsten based alloys are regarded as an ideal electro-heat upsetting block materials and "inbourn" die materials[1-4]. The combination of their high strength and hardness, good electrical and thermal conductivity, good corrosion and oxidation resistance makes them not deform at high temperatures and have good stability at high pressures.

However, in the process of electro-heat upsetting, the tungsten alloy anvil exposes in the air at 900~1150 C and under a pressure of 180~250 MPa and thier surfaces suffer from great thermal-mechanical stress and ambient corrosion. After being wrought many times, the surfaces oxidated seriously and formed holes or moires. The electrical and thermal conductivities become worse, and consequently the anvil life and air valve quality were influenced.

With the development of electro-heat upsetting process and its wide application in the world, scientists have made great efforts to study the anvil materials so as to improve the productivity and quality of the air valves. The development of steel or thermal counter steel was used, but the productivity was very low and the energy consumption was very high, and they could not upest harder steels because their strength and hardness at high temperature decreased immediately. Then, Cu-W80 alloy was used and the anvil life was increased twice as much. Thanks to the 20wt. -% content of copper, when the upset-

ting temperature exceeded the copper melting point, the copper began to melt, and leaded to form holes easily. By the end of 1970's, the heavy metals have used as upsetting blocks. They can improve the anvil life twenty times more than that of Cu-W80 alloy, and have come into wide use in the world. Therefore, it is of practical importance to investigate the breakage mechanism during electro-heat upsetting for directing materials research and improving the proporties of the alloys.

2   EXPERIMENTAL

The heavy alloy anvils used in the experiments were prepared in the same method as in factories. Their σ_b were better than 900 MPa, HRC equaled 28 ~ 31, and metalloygraphical structure distributed well. Before electro-heat upsetting, they must be consolidated to the substrate using copper welding. The materials of the air valve were 40Cr, 4Cr10Si2Mo, 4Cr9Si2, 21-4N, and so on. The technological parameters were; second voltage, 2 ~ 2. 37 V; oil pressure, 180 ~ 250 MPa; upsetting temperature, 900 ~ 1150 C。 And those parameters were varied with the valve materials. After electro heat apsetting we analysed the phases by X-ray diffraction on the damage surface, observed

their microstructure and composition variation in tiny areas with X-650 scanning electron microscope and NEOPHOT-21 metallograph microscope, to study the damage behavior and mechanism of tungsten anvils.

3   ANALYSES OF THE BREAKAGE MECHANISMS

During the electro-heat upsetting, the anvil surface suffers greatly thermal-mechanical stresses from 900 ~ 1150 C high temperature and 180 ~ 250 MPa upsetting pressure, and altarnatively corrosion and thermal-mechanicel fatigue in special, thus result the anvil in break. The breakage mechanism can be described as follows.

At high temperatures, the surface temperature of the anvil increases immediately. After upsetting for a time, tungsten, nickel, iron and molybdenum oxidiated together. Fig. 1 is the result of X-ray diffraction of damage surface of the alloy.

The result is that electrical-thermal conductivities of the tungsten alloy decrease, the surface temperature increases and the anvil gets red. When the temperatures are over 800 C, tungsten and molybdenum oxides begin to evaporate violently[5-7], especially, the sublimation speed of the tungsten oxide
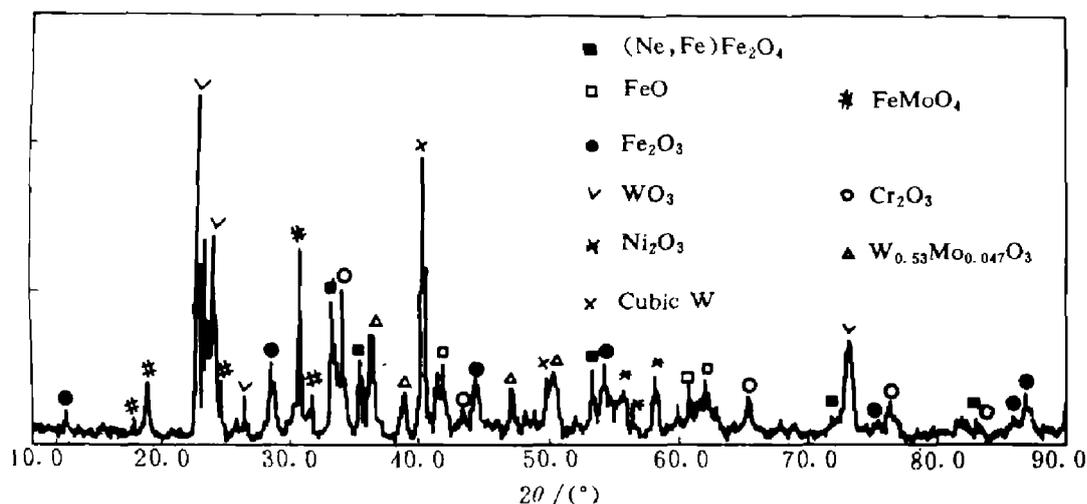

Fig. 1   X-ray diffraction after electro-heat upsetting of Anvil material

equals its formation speed over 1 100 C[6]. For the Ni-Fe binder when the temperatures exceed its softening temperature(0. 5~0. 6 T_m), nickel begins to evaporate violently because of oxidation[8, 9]. At the time there is strong electron movement in the process of electric contact. Iron and chromium in the steel migrate to the anvil. Table 1 shows the results of the composition analysis in tiny areas of the breakage surface.

Oxidation, evaporation and migration of the material make the tungsten alloy anvil form holes. We can find a lot of adhension materials and tiny holes and trenchs from its microstructure. Cracks form easily at these defects.

Table 1　The composition analysis in tiny areas of the breakage surface/wt. -%

	W	Mo	Fe	Cr	Ni
the alloy before upsetting	90	2	2. 7	0	5. 3
anvil damage surface after upsetting	13. 8	0. 70	54. 9	28. 5	2. 77
near part of anvil damage surface after upsetting	74. 3	0. 91	14. 7	1. 72	9. 33

The temperature of the central part of the anvil is higher than those of the other parts, thus a radial temperature gradient forms. In the process of heating and cooling, there are thermal stresses for thermal expansion and cold contraction. Cracks spread in radiant shape in the horizontal planes, see Fig. 2. At high temperature, a part of the plastic deformation occurs, and tungsten grains become flat and grow up(Fig. 3). In the meantime, the high upsetting pressure, result from great stresses in the vertical plane, at the central part, and cracks spread in 45° direction.

The spread of thermal- mechanical fatigue crack is equal to constant strain fatigue[11]. Because of plastic deformation oc-

curing at the condition of thermal-mechanical fatigue, it is suggested that stress strength coefficient $\triangle K$ is replaced by strain strength coefficient $\triangle K_\varepsilon$, $\triangle K_\varepsilon = \triangle K/E$, the speed of crack spread; $dA/dN = G_1 \times (\triangle K_\varepsilon^m)$, $\triangle K_\varepsilon^m \propto \triangle \varepsilon$. Therefore, the greater the plastic deformation, i. e, the greater the strain area is, the faster the crack spread.

Fig. 2　Crack growth metallograph in the plane at 1 mm distance from surface(× 10)

At high temperature, metal oxidation accelerates thermal-mechanical fatigue crack formation. On one hand, the oxide film is damaged constantly due to cycle loads, promoting partial oxidation, forming gap effects and concentrating strain area. thus accelerating crack to grow. On the other hand, the inconsistency of thermal expand coefficient among different oxides and between oxide and base alloy, cause the thermal fatigue damage. On the mutual affect of the corrosion and thermal- mechanical fatigue, the crack source is not only one, fatigue cracks spread along grain interfaces. intersect each other and form moire cracks, see Fig. 4.

The first reason for crack spread along grain bondaries is that W- binder combined strength itself is low. Secondly, the corrosion medium makes the oxides and impurity boundaries with more defects. and when

Fig. 3   Microstructure variety before and after electro-heat upsetting(×300)
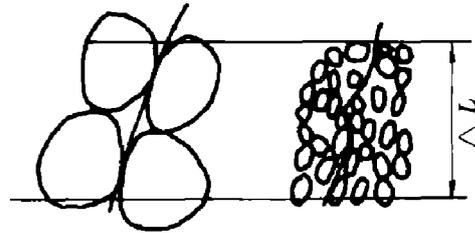
(a)—before;   (b)—after

Fig. 5   Crack growth model ($\triangle$ L —the length of crack)

Fig. 4   Crack growth SEM photograph at 0. 5 mm distance of surface(×600)

tungsten based alloy suffers from enormous thermal-mechanical mutual stresses, boundaries damage is prior to grain damage, which cause cracks spreading along W-binder and Ni-Fe binder in branches.

Microstructure has influence on crack formation and spread. Grain refinement makes the numbers of dislocation which freely slide to pile up, stress concentration decrease, and cracks hardly form. When there are a lot of second strengthening phases and second particles on the crack along grain boundaris do not produce easily. The time of the crack spreading in alloy is directly relative to grain size. For Coarsened-grain alloy, crack spread fast along W-bonder and binder. Meanwhile, the increase of W- W

contact promotes crack spread, see Fig. 5. Therefore, fine grain material have better fatigue property. The large brittle phase, impurity and twin interface in alloy can promote cracks to form and make the alloy life decrease.

The existence and spread of cracks also provide unimpeded paths for metal oxidation, evaporation and material migration nearby cracks. Material migration, oxidation and evaporation will occur within deeper areas. Thus, in the depth of one millimeter from surface, tungsten grains decrease greatly, microstructure and composition also vary. The composition analysis of the plane at 1 mm distance from surface show that in the poor W area, W is only 5. 33, Mo is 0. 86, Fe is 92. 92, Cr is 0. 88(wt. -%).

Therefore, the result of interactions is that the cracks have spread into deep scope,

W-binder boundaries of low strength have been influenced seriously.

4 CONCLUSIONS

(1) In the process of electro-heat upsetting the tungsten alloy anvil is influenced by the mutmal functions of corrosion/ thermal-mechanical fatigue and is led to damage.

(2) Because of the oxidation, evaporation and migration of the alloying elements, crack sources form easily. Due to the mutual functions of the corrosion stress and the thermal-mechanical fatigue, the crack spread rapidly along the grain boundaries .

(3) Well-distributed tiny grains material has better fatigue property. Large brittle phase and impurity in the alloy can make life lower.

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