the stresses causes and or enlarges the cracks near the collar of the rod where the cross section changes its form and size, and later on some large tension stresses break the rod. This explains the affairs. One must be careful about the scars on the surface or the collar part and must not handle the rod roughly.

Some words on the dynamic buckling of an elastic bar are added. The eccentricity of the blow, which is most likely to exist in any case of axial impact, seems to perform the principal role also in this case.

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Micro-Structural Observation on Fatigue Fracture of Metals

By Shigeo OWAKU* and Seinoshin MORIKAWA**

It has been micro-structurally studied why the fatigue fracture of metals appears smooth and shelly; white or black.

The study has revealed that the fatigue fracture, initially rough, becomes smooth under repeated stress; the metal dust produced is sintered, and in the case of high-carbon steel quenched-hardened, under friction heat, into a very hard material.

In this process, if air enters into the crack, the color of fracture surface will turn to black owing to the influence of friction heat; otherwise, it would be white.

Generally speaking, fatigue fracture of metals looks smooth and shelly. Its color is sometimes white, sometimes black. Fig. 1 illustrates a white fatigue fracture appearing in the head of a rail. Numerous investigations on fatigue mechanism and fatigue strength have been reported, but none of any metallographical study into fatigue fracture so far as the authors are informed. The authors therefore attempted to contribute to the latter study and carried out micro-structural observations on fatigue fractures developing in mild and hard steels. The following are the summarized results.

1) **Mild steel** The profile of fatigue crack appearing in a mild steel specimen (0.2%C) subjected to Ono's repeated rotary bending test is illustrated in Fig. 2. The area of this crack as indicated in Fig. 3 has been micro-structurally examined. The results revealed, as shown in Fig. 4, that the fibrous structure of material has lost its

Fig. 1 Fatigue fracture in rail head

directivity, where it is bounded by cracks, and is drawn toward cracks, with finer grains of crystals. It shows that the crystal grains, having been rubbed together between cracks, have been cold worked. According to measurements, the hardness of the

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Fig. 2 Profile of crack $\times 3$

Fig. 3 Site of Microscopic inspection

Fig. 4 Microscopic structure of crack

area between cracks is Hv 236 as against Hv 190 of virgin material, about 25% increase over the latter. It goes without saying that such relationship of hardness may very depending on the magnitude of internal stress. Anyway it cannot be disputed that there is a structural disturbance and increase

in hardness observed in fatigue fractures.

2) **Hard steel** Fig. 5 represents a fatigue fracture occurring in the interior of a tyre (0.7% C). Fig. 6 indicates the site of microscopic observation. Fig. 7 illustrates the structure of material, which is pearlite plus ferrite. As the microscope is

Fig. 5 Fatigue fracture in the interior of tyre

Fig. 6 Site of microscopic inspection

Fig. 7 Structure of material $\times 100$

shifted along the fatigue fracture, the interior of crack discloses an abnormal structure as seen in

Fig. 8 Structure of crack tip $\times 100$ Fig. 9 Structure of originating zone of crack $\times 100$ Fig. 10 Structure of originating zone of crack $\times 100$ Fig. 11 Structure of abnormality $\times 300$

Fig. 8 of progressing tip of crack, Figs. 9 and 10 of originating zone of crack.

Fig. 12 Structure of abnormality $\times 300$ Fig. 13 Structure of abnormality $\times 300$

Figs. 11–13 show the enlarged structures of this abnormality. Such abnormality happens in whatever parts of crack and its magnitude differs. As its metallic lustre before etching testifies, the abnormality is undoubtedly a substance of metallic nature. Under magnification it looks shelly and this structure contains numerous cracks, suggesting that it is very brittle. Its hardness is Hv 730–1 080, which is a very high value of hardness. Such high value is found nowhere except heat-treated carbon steels, and cannot be expected from simple cold working. For instance, piano wires, which have been 90% worked (wire-drawn), have Hv 542, which is short of the hardness characteristic of the metallic abnormality under study. Thereupon this abnormality must be interpreted as of hardened structure.

To confirm this interpretation, the authors annealed similar specimens at 800°C for 30 minutes and found, as anticipated, that the structure was pearlite plus ferrite as shown in Figs. 14 and 15, with hardness Hv 150–250.

From these facts it has been concluded that here and there along the fatigue cracks, abnormalities develop containing martensite structure (hardened structure). This observation is not confined to the specimens tested, but also applicable to some tyres later examined. Fig. 16 represents one of

such cases, the white streak in the picture being the abnormality of martensite structure. Such abnormality is presumed to originate from initial crack developing in the interior of a tyre. Under heavy pressure and friction the rough surface of the crack turns smooth; the metal dust produced as a result of wear is then sintered by friction heat; quenched and hardened in the huge mass of tyre. The abnormality must have grown out of this process successively repeated. Seemingly this explains the shelly look and martensite structure of

Fig. 14 Annealed structure of abnormality $\times 300$ Fig. 15 Annealed structure of abnormality $\times 300$ Fig. 16 Example of abnormality observed in another tyre (white streak in the centre indicates abnormality) $\times 300$

it. It should be noted that martensitic change of structure causes volume increase and embrittlement, which is considered to promote fatigue cracking.

To sum up the foregoing, the fatigue fracture, initially having a rough surface, becomes smooth under repeated stress; the metal dust produced, having no escape, is sintered by friction heat, and even hardened in the case of high-carbon steel. Since temperature rise due to friction heat is substantial, the crack with presence of oxygen presents a black, smooth fracture; the one without oxygen

a white, smooth fracture. This phenomenon is a characteristic of such objects as tyre or rail that have a large mass under enormous external force and contain fatigue cracks lurking within, with the worn metal dust trapped without any outside escape. Proceedings AREA (Vol. 56, 1955) also reports that a similar abnormality was found in a fatigue fracture (transverse fissure) occurring in a rail-head, registering Hv 1 200 as against Hv 300 of material.

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External Pressure Produced by Multi-Layers of Rope Wound about a Hoisting Drum*

By Tadashi EGAWA** and Motoharu TANEDA**

The writers of this paper carried out theoretical and experimental investigations in order to ascertain precisely how the external pressure exerted on a hoisting drum by multi-layers of rope wound around it under tension increases as the number of rope layers is increased.

Experiments were performed on model drums by winding ropes under constant tension and the circumferential strains produced inside the drum shells were measured. The number of layers was increased up to eight.

As far as the research extended, the experimental results coincided well with the theory of the authors. The ratio between the increase in the external pressure on the hoisting drum and the number of rope layers grew the larger as the rigidity of the drum increased and the modulus of elasticity of the rope decreased. Conversely, the smaller the rigidity of the drum and the greater the modulus the smaller was the ratio. The ratios of Mr. Waters which have generally been adopted are smaller than those of the authors and are on the dangerous for the designing of hoisting drums.

1. Introductory

There is, so far as we know, little or no literature on the external pressure to which a hoisting drum is subjected when a rope is wound in multi-layers about it under tension, as in the case of a winding machine used in a mine. However, the only paper that we have come across and seems reliable in a way, is the one by Mr. Waters⁽¹⁾. But Mr. Waters' paper contains numerical values that presumably have been computed theoretically

but he has not indicated his theoretical formulas. According to him, the external pressure on the hoisting drum scarcely increases when the rope is wound about it more than four layers. We believe that this is a point that must be looked into a little further.

Accordingly, we have studied the point theoretically and, at the same time, we wound a rope around a model drum and observed the changes in the external pressure as the number of rope layers was increased.

As a result, we have obtained numeral values different from those of Mr. Waters.

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