THE SAFETY OF JOINT COMPONENTS OF HOISTING DEVICE EMPLOYED IN A COAL MINE SHAFT

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The quality of a joint component connecting the winding rope and the cage used in a shaft is very much concerned with human safety and coal production of the mine. According to the regulation issued by the Ministry of Coal Mining. "The joint must be replaced every five years and should not be used again unless it is proved to meet the safety requirement through non-destructive inspection".[1] In order to make the replacement in the Cai Tun Coal Mine, batches of new joints have been produced. The results of Ultrasonic inspection shows that large amount of internal defects are present in the new joints, a question naturally arises to what extent the defects can be tolerated under working condition in Cai Tun Mine.

To answer this question, samples were taken from the new and old products (the old ones have been used over 14 years), a series of test were carried out, from which, fatigue life and critical size for the defect under the working circumstances in Cai Tun Mine were estimated. The result of this research can be used to consider the possibility of using those joints in Cai Tun Mine. Meanwhile, it may also be taken as a reference for other coal mines with similar working conditions.

WORKING SITUATION ANALYSIS

A sketch of the component is shown in Fig. 1. The side plate was fabricated from a rolled plate of 60mm in thickness. The universal joint and connecting plate were both made of forging . The new and old products were made of 35# and 15# steel respectively. The parts were normalized at 860°—880°C after rough machining.

In service, the joint is subjected to a unidirectional and alternating tensile force. The minimin load is 14.9 tons, while the maximum is 37 tons. The stress ratio $R(P_{min}/P_{max}) = 0.4$. The alternating load cycle is repeated 500 times every working day. Furthermore, there can be a dynamic load applied onto the joint during emergency braking. Under some other particular circumstances, such as when the cage is suddenly stopped in the shaft or over winding with original speed, etc., accident may happen. In such cases the joint is subjected to a very large dynamic load.

The temperature in the working situation lies between 0°C and 30°C.

Ultrasonic inspection was carried out on the new and old joints. It has been found that closely spaced laminated defects exist in large area in the interior. In the new joints, the maximum width of the defect area is 180mm, the maximum flaw echo is equivalent to φ6 in the area. In the old ones the width of the defect zone sometimes can almost be equated to that of the joint iteself, the corresponding maximum flaw echo is even larger than φ10 equivalent area.

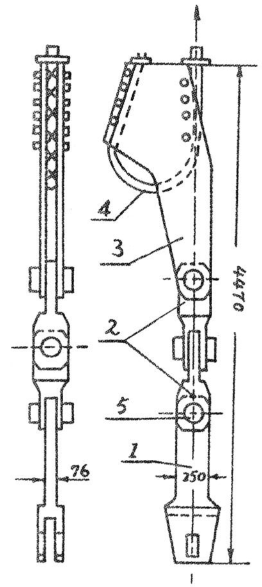

Fig.1 The joint component sketch

1. Connecting plate
2. universal joint
3. side plate
4. winding rope
5. connecting shaft

EXPERIMENTAL RESULTS

1. J-Integral Measurement

The tests were carried out according to the regulation of standard[2]. The dynamic experiments were carried out according the standard[2] too, except the loading speed was taken $\dot{K} = 6.4\times10^4 kgf/mm^{3/2}/s$.

The testing results obtained at 14°C from forging and rolled part with and without defects have shown that owing to the metallurgical factors the resistance curves scatter widely in a band and the J-integral values for forgings lie in upper portion of the band. Meanwhile the J-integral values of flawed specimens lie above those of unflawed ones. The other tests were carried out on specimen cut from rolled plates.

Similar tests were performed in the old joint of 15# steel. The results obtained are tabulated in Table 1.

Table 1

steel	test T°C	quasi-static loading			dynamic loading		
		J_R(kgf/mm)	$J_{0.05}$	$J_{0.2}$	J_R(kgf/mm)	$J_{0.05}$	$J_{0.2}$
35	25	J_R=6.0+17.1Δa±1.7	7.7*	10.3*	J_R=1.4+11.8Δa±0.5	2.3	4.05
	0	J_R=2.0+13.7Δa±0.5	3.1	5.5	J_R=2.9±0.9		2.9**
15	25				J_R=0.6+19.6Δa±1.4	2.2	5.05
	0		5.9***	11.3***	J_R=2.8±1.1		2.8**

* The temperature during test was kept at 14°C.

** Brittle fracture, da < 0.05 mm, J_{1c} value is calculated according to maximum load, and the maximum error is marked.

*** $J_{0.05}$ takes the lowest limit of brittle cracking. $J_{0.2}$ value is calculated according to the maximum load (Δa=0.11 mm).

2. Measurement of Fatigue Crack Growth Rate

Since the loading frequency does not have mush effect on da/dN values within the low ΔK region, a higher frequency than that in practice is adopted in our tests.

Taking the ΔK value at da/dN = 10^{-7} mm/cycle as the threshold stress intensity range ΔK_{th}. The result obtained from experiments are shown in Table 2.

Table 2

Steel	ΔK_{th} kgf/mm$^{3/2}$	1st stage da/dN mm/cycle	2nd stage da/dN mm/cycle
35	28—30	da/dN=$5.1\times10^{-21}\Delta K^{9.23}$	da/dN=$2.1\times10^{-7}\Delta K^{1.21}$
15	25	da/dN=$1.3\times10^{-29}\Delta K^{15.5}$	da/dN=$3.8\times10^{-7}\Delta K^{1.06}$

3. Defect Analysis

Samples were taken from the seriously flawed portion of new and old joints and then the macro-examination was performed. The macrographs of the cross section are shown in Plate 1 and 2, respestively. Metallographic

examination reveals the presence of numerous clustered or lined oxide and sulphide inclusions and lamellar cementites within the defective area. The dimension of the defect is usually very small in the thickness direction of

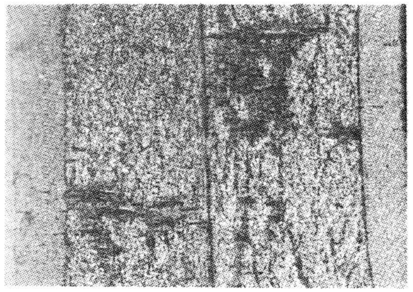

Plate.1 The fracture surface of a new joint 2 X

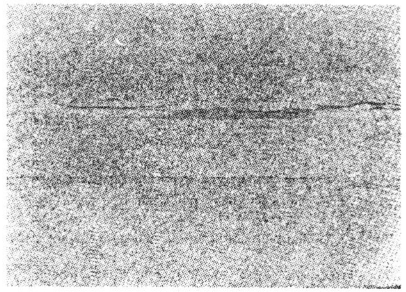

Plate. 2 Macrograph of the cross section of a old joint 0.5 X

the joint (<2mm), but it is relatively large in the length and width directions. For the new joint, most of defects are small, but in some regions there are a few large defects. The defective zone is within 15mm along the thickness. For the old joints, the laminated defects are located within 8mm of the thickness.

ESTIMATION OF FATIGUE LIFE AND SIZE OF CRITICAL FLAW IN A JOINT

Estimation was made for the connecting plate, but the result of the estimation is equally applicable for other three parts.

Since the defects in the joint are distributed as clusters in 3 dimensions, and the laminae formed are parallel to the direction of external force, they tend to stop the crack extension in the direction perpendicular to the force, consequantly, they act to increase fracture toughness. This is confirmed by the experimental results. If they are simplified and treated as 2 dimensional defects lying in a plane perpendicular to the extrenal force, the estimation will be on the safe side. Furthermore if a zone of clusters of small cracks is treated as a large crack of the size of the zone, a safe estimation is obtained.

1. Estimation of Critical Size for Tolerable Defect

The most dangerous case is the occurrence of an accident such as overwinding with full speed or sudden stop of the cage in the shaft, especially in winter. An extremely large dynamic load is transmitted to the winding rope, as well as to the joint component. The regulation claims that when the cage is fully loaded, the safety coefficient of winding rope should not be less than 7.5[1]. The safety requirement urges that the winding rope should break before the joint component during an accident. Therefore the dynamic loading coefficient of the joint should not be less than 8 (in measuring J_R values, it was assumed that 0.5 second is needed for rope or skip to transfer a force onto the joint component and to increase it to a value of 8 times the maximum static loading).

(1) Estimation for ordinary section

All the cracks are simplified and treated as a big interior elliptical crack. Due to the limited width and thickness of a joint component, thickness correction coefficient M_1 and width correction coefficient F_1 are used. Thus the expression for stress indensity factor K_1 at the tips of the b axis of an elliptical crack is: $K_1 = F_1M_1\sigma(\pi b/Q)^{\frac{1}{2}}$[3].

The lower limit of experimental results for dynamic loading at 0°C is J_{1c} = 2.0 kgf/mm, and K_{1c} = 214 kgf/mm$^{3/2}$, by using formula $K_{1c}=(EJ_{1c}/1-\nu)^{\frac{1}{2}}$. Since the number of J_{1c} estimation from the experiment is not statistically sufficient, the J_{1c} taken as above may not be the lowest one, Therefore, K_{1c} = 150 kgf/mm$^{3/2}$ is taken for the sake of security. Stress should be taken as 8 times the maximum value under static loading condition, thus σ = 2 × 8 = 16 kg/mm². The residual stress is taken to be 10 percent of σ_s value, i.e. 3 kg/mm². Therefore the working stress is evaluated to be 19kg/mm².

Hence the dimension of a critical crack may be calculated as 2a × 2b (mm) = 19 × ∞ (through crack), 130 × 30, 170 × 20, 220 × 10.

(2) Estimation for the cross section containing a hole.

Due to the fact that loading is transfered as a concentrated force through a connecting shaft to the portion above the hole, the danger caused by a defect can be different when it situates at different place on A-A section. The cracks growing outwards from both sides of a hole are considered to be the most dangerous ones. Evaluation is carried out on the basis of the above mentioned case as shown in Fig. 2. Considering the correction of width as well as thickness, the stress intensity factor expression becomes: $K_1 = MF_1M_1P/2rh(\pi b/Q)^{\frac{1}{2}}$[3], where M is a calibration coefficient and h represents the thickness of the plate, here P = 8×37000 = 296000 kg, k_{1c} = 150 kgf/mm$^{3/2}$, taking into account the residual stress of 3 kg/mm². The result for a×2b mm of through crack becomes: 4 × ∞,

15×8, 30×6, 50×5, 60×4.

Practically no defect were found along the cross section containing the hole. In ordinary cross section, maximum size of a single defect is 18 × 2 (mm), which is much less than the estimated value. If the interactive effect among the closely spaced defects is considered, these defects should be treated as a whole as a large crack. Even though, the maximum size of defect zone found by ultrasonic detection in ordinary cross section is 180 × 15mm, which is still less than the above estimated value. Therefore the joints can be used safely.

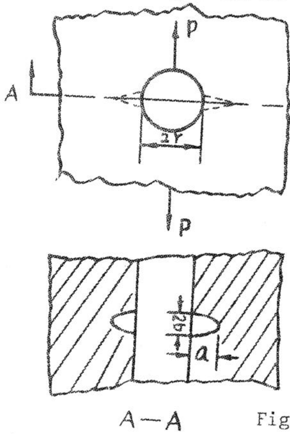

Fig. 2

When the joint is working in a dynamic loading conditon at 0°C, J_{1c} of 15# steel is the same as that of 35# steel. For the old joints, the maximum cross section of defect zone is 250 × 8mm. Furthermore, it had been used safely for 14 years. This is a proof of the conclusion obtainedin our inverstigation.

2. Fatigue Life Estimation

The threshold stress intensity range ΔK_{th} and the load amplitude ΔP are known as 28 kfg/mm$^{3/2}$ and 22180 kg respectively.

(1) For ordinary cross section

The central through cracks are assumed here in order to simplify the calculation. i.e, $\Delta K = F_1\Delta\sigma(\pi a)^{\frac{1}{2}}$[3].

Let $\Delta K = \Delta K_{th}$, solving the above equation, we get a = 85 mm.

(2) For the cross section along the hole

Again through cracks are assumed to lie on both sides of the hole. Then $\Delta K = FF_1P/2rh(\pi a)^{\frac{1}{2}}$[3] where F is the calibrating coefficient taken as 1 (maximum).

Let $\Delta K = \Delta K_{th}$, solving the equation, we get a = 39 mm (no width correction is carried out since the maximum value of F is taken).

It is known from the above calculations that unless the defect size has attained the values stated above, there is no possibility of crack growth under alternating load condition. However, these values are much greater than the estimated critical value for tolerable defect a_c, which means that a crack in a joint will not grow while the joint is in use, that is to say its fatigue life is "infinitely" long.

The ΔK_{th} value obtained in testing the old joint made of 15# steel is lower than that of $35^{\#}$ steel. There is no fatigue growth at all in the old joint which have been subjected to alternating loading for about 3×10^6 cycles.

CONCLUSION

1. Since the alternation stress that a joint is subjected to is very low, fatigue crack growth will not take place while the joint is in use.

2. Using the fracture toughness under the dynamic loading at 0°C and taking 8 times the static stress as the dynamic loading the critical size for tolerable defect (2a × 2bmm) evaluated for ordinary cross section is 220 x 10, 170 x 20, 130 x 30 or 19x∞, and that for the cross section containing the hole (2x2bmm) is 4x∞, 15 × 8, 30 × 6, 50 × 5 or 60 × 4. These flawed joint can be used satisfactarily because their defect sizes are much less than those limits stated above.

3. The ΔK_{th} and J_{1c} value under dynamic loading at 0°C for the old joints are the same as that for the new ones, therefore the experience in safety obtained from the old joint can be employed as a proof for above estimation.

REFERENCES

[1] "Safty Regulations for Coal Mine" Ministry of Coal Mine Industry (1980).

[2] GB 2038-80, Chinese National Standard (1980).

[3] Handbook of Stress Intensity Factors, ed. by CAI (1981).