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THE FRETTING DAMAGE AND EFFECT OF TEMPERATURE IN TYPICAL JOINT OF AIRCRAFT CONSTRUCTION

T.Z.Tian
Shenyang Aircraft institute
Shenyang, Liaoning, P. R. CHINA

Abstract

The fatigue test results and the fatigue fracture for three types of joints, i. e. bolted joints, set–head rivet joints and countersunk rivet joints of the aluminum alloy, have been studied on the basis of more than 200 joints test at both elevated temperature and room temperature. It is revealed that the cracks initiated in the places where fretting had taken place and led to the failure of fretting fatigue. Different types of joints cause different modes of transmitting loads so that the places of cracks changed, which result in difference of fatigue strength.

In this paper, the effect of fretting damage on fatigue strength and the effect of elevated temperature on fatigue strength and fracture appearance are also presented.

1. Introduction

There are many practical applications in which moving components of machines are required to function at elevated temperatures. In certain cases, particularly in the jet engine and power generation fields, it is necessary for components to encounter whith aerodynamic heat, force convection and heat radiation, sliding occurring between the contaction surfaces. Under these circumstances the removal of material from the mating faces, i.e, wear, is likely to occur. Where the movement is oscillatory and of small amplitude, the movement may arise from unavoidable machine vibration, or from the cyclic stressing of one of the components, in which case the more serious consequence is the possible initiation and propagation of fatigue cracks at alternating stresses far below those at which such cracks would be initiated in the absence of fretting.

In this paper the fatigue fractures that can be observed by electron microscope and the effect of temperature for three types of joints, i.e. bolted joints, set–head rivet joints and countersunk rivet joints, Figure 1–3, of the aluminium alloy sheets have been studied in which more than 200 specimen test result of typical joint in aircraft construction have been analyzed.

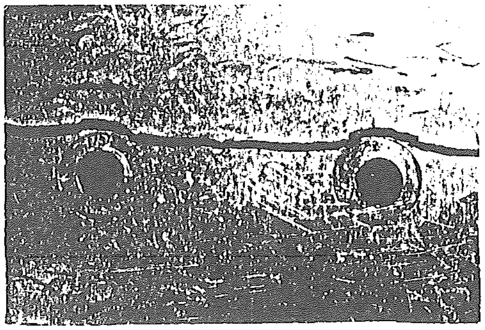

Figure 1 bolt connect joint

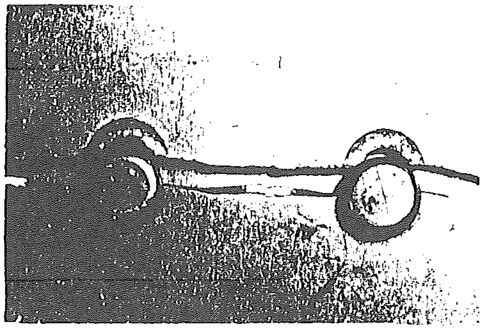

Figure 2 set–head rivet joint

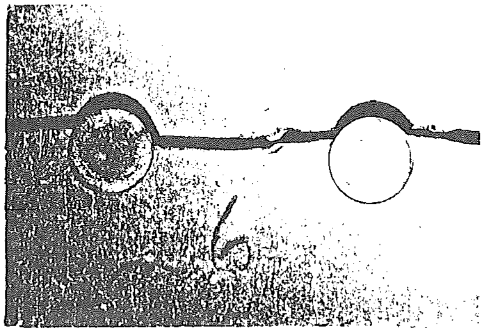

Figure 3 countersunk rivet joint

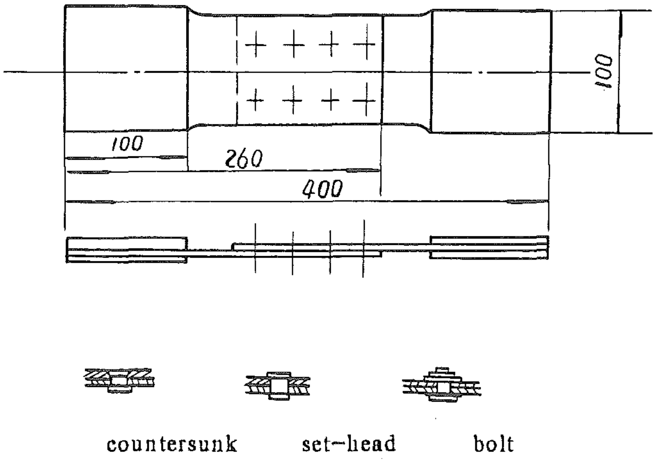

Figure 4 specimen diapgram

2. Experimental

The specimen of three types of joints, described in the previous sections, are designed, an adjunct to a programme of fatigue testing or appearance of the geometries see Figure 4 and see reference 1.

Material is aluminium alloy Ly−12cs, nature ageing. Specimen thickness is 1.5mm with surface anodie treatments. $\sigma_b \geqslant 450$mpa, $\sigma_{0.2} \geqslant 295$mpa, $\delta_{10} = 10\%$. Bolt is HB−105−5× 14, accuracy H9, Washer is HB 6× 10× 2, Set−head rivet is H 5× 9 GB868−LY−10. Countersunk rivet is H 5×9 GB 954−Ly10, 120 ° . Test were carry out in push−pull machine.

Test Conditions

All test were carried out in conditions of different load, temperature and heat exposure time. Details of these tests were discribed in reference 1.

The result

Results of tests for all joints of the series was presented following in Figure 5 to Figure 7.

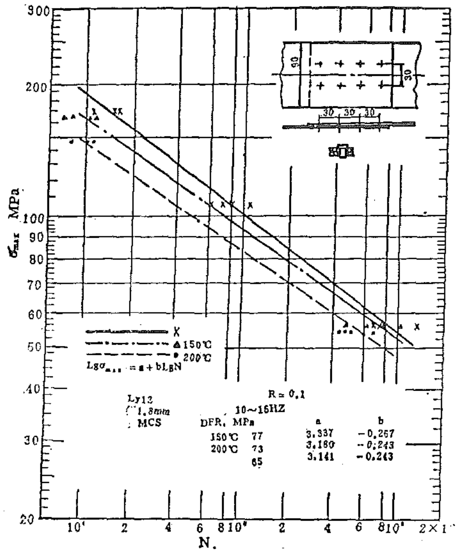

Figure 6 S−N curves for set−head rivet joint—material LY−12MCS

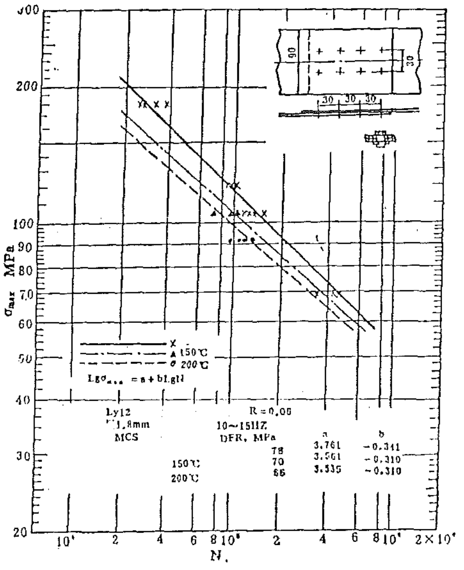

Figure 5 S−N curves for bolt joint— material LY−12MCS

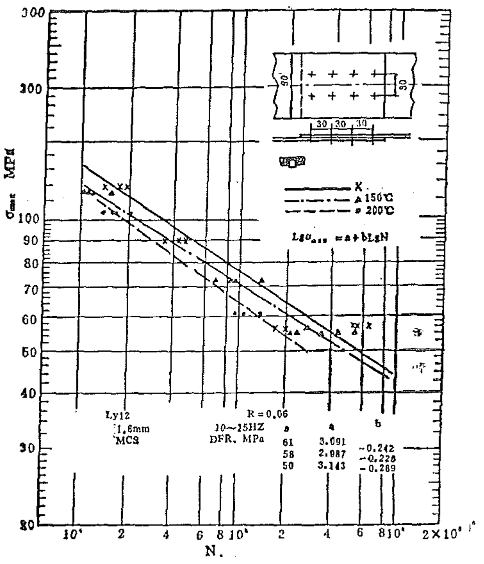

Figure 7 S−N curves for countersunk rivet joint—material LY−12MCS

3. The effect of fretting on typical joint fatigue strength

Figures 1–3 and table 1 shows cases of fretting fatigue in typical joints of aluminium alloy aircraft skin stringer attachments. It is clear that cracks initiated in the places where fretting had taken place and led to the failure of fretting fatigue. Different types of joints caused different modes of transmitting load so that the places of cracks changed, which results in the difference of the fatigue strength

Bolt joints: Because of higher clamping pressure, the bolted joints can transmit load by static friction between the washers and the sheets. Fretting fatigue cracks initiated at the edge of contact between the washers and the sheets. Figure 1 clearly shows an example where the fretting scar circumscribes the fastener hole and where the fatigue crack has been influenced more by the fretting than by the geometric stress concentration of the hole itself. It also can be seen that the fretting fatigue crack initiated not at the point of geometric stress concentration of edge of hole, but somewhat higher up the side of that circumscribes the fastener hole where fretting can override the geometric stress concentration presented. The fatigue strength of this type of joints is the highest.

Countersunk joints:

The clamping pressure of countersunk rivet joints is lower, the transmitting load must therefore go through the rivet rods and the rivet holes where fretting occurs. Fretting fatigue cracks initiated along the diameter perpendicular to the load direction. The stress concentration caused by fretting piles up, see figure 8 that of the sheets and the crack initiation. Therefore, the fatigue strength of this type of joints is the lowest.

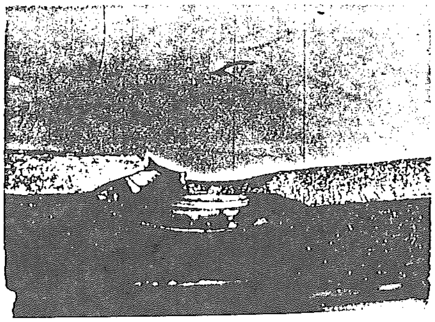

Figure 8 Countersunk rivet joint fracture appearance of fretting scar

Set–head joints:

The transmitting load of set–head rivet joints is situated between the above–mentioned joints so that their fatigue strength is also in between.

4. The effect of temperature on typical joints fractures appearance

The effect of temperature on fretting damage and fracture appearance in three types of joints is showed following three aspects.

- The effect of temperature on mechanical properties of the materials is showed in figure 9

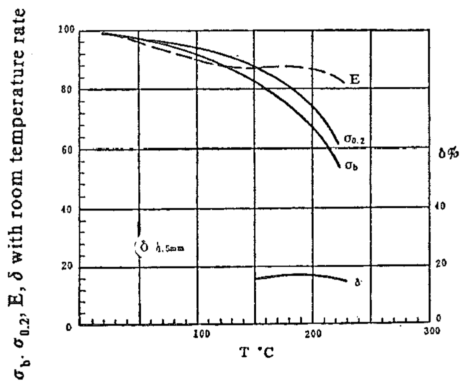

Figure 9 the velation between σ_b. $\sigma_{0.2}$, E, δ and temperature

- Increased oxidation rate of aluminume alloy with elevated temperature
- Because fatigue test time is long and involves tension load, accompaning creep occured at elevated temperature tests.

Effect of these three factor united and interacted upon fracture appearance.

(1), It has long been realised (see reference 2) that the surface oxide films that form naturally on metals can be very effective in reducing wear between contacting metal surfaces. At elevated temperatures in oxidising environments, flim on metal surfaces grow to greater thicknesses and generally retain good protective properties. However there is evidence that a number of fatigue test results at temperature 150℃ exhibited increase wear rate and any process which disrupts the integrity of the protective layer may have harmful consequences: the mechanical action of fretting is one such process. Thus when fretting and oxidation occur simultaneously there is every likelihood that the process of oxide formation will be affected by the fretting action. Equally, the nature of the oxidation product can itself have a maked influence on three types of joint and type of damage produced during fretting. Several effects are possible including disruption of the oxide film producing abrasive debris which accelerates wear, or indeed complete removel of the oxide allowing metal–to–metal contact, local adhesion, possible seizure and surface gouging with subsequent effects on fatigue life.

Table 1 The fracture places for three joints and auerage fatigue strength

connectform	number (LY–12)	cracks initiated place and ptrcentage rate						average fatigue strength
		edge of washer	%	edge of hole	%	diameter	%	
bolt	50	46	92	1	2			5.58
countersunk	37			9	24.3	28	75.7	4.40
sethead	35			24	68.6	11	31.4	4.98

Interpretation of these situation see figure 10–11. Figures 10 and 11 compared fracture appearance at temperature 150℃ or at room temperature. Both of them are experienced cycle 10^6, figure 10 shows an example of this where anodised oxidation layer was clearly fragmented and churned up by the heavy scuffing action that developed in elevated temperature. Figure 11 shows a result of room temperature of where not only anodised oxidation layer presented, but alse surface snooth and slighter fretting action.

(2), Figures 8. 12 and 13 show cases of fretting fatigue in set–head rivet joint, countersunk rivet joints and bolt joints in aluminium alloy Ly–12 aircraft skin stringer attachments where not–uniform closure conditions have existed and point breakdown has occurred both at the skin / stringer interface and under fastener heads and also where, by the design, local rubbing points exist at the edges of dimpled holes. There have been clad with ralatively soft aluminimm(alclad). This cladding, being soft, is particularly prone to stage 1 fatigue cracking produced early in the life of the part. Add to this reason, introduciug such as fretting, temperature rubbing, oxidation, which also has the effect of producing early cracks, at the sometime oxygen infused new micro–cracks surface accelerated parent oxidation as if "awage" action. In addition, the softer coatings may be deformed and a large burr will form all these accelerated micro–cracks propagation.

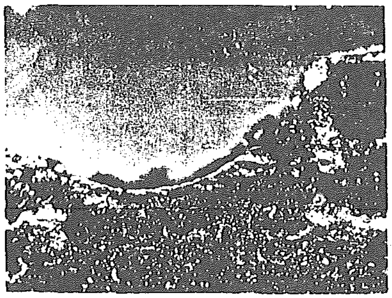

Figure 10 fretting damage made oxidation accelerated LY–12 bolt joint at edge of washer 150℃ . experienced 10^6cycle, (×10)

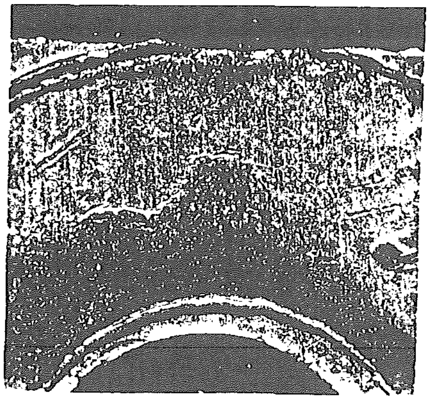

Figure 11 bolted joint It is experienced 10^6cycle. surface smooth. oxidation slighter (×10)

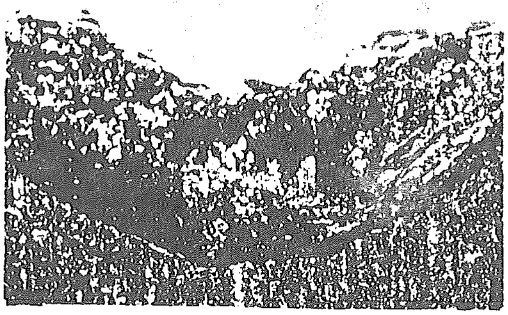

Figure 12 Fretting or rubbing made breakdown contact surface, oxidation accelerated in LY–12 set–head rivet joint 150℃ experienced 10^6cycle (×12)

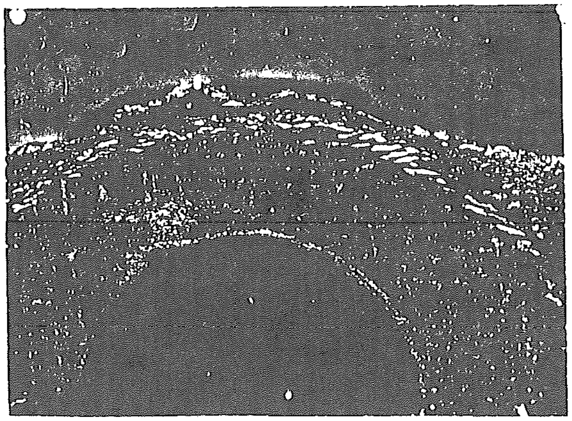

Figure 13 Non–uniform closure or rubbing oxidation made extrusion deformation in edge of washer, crack initiation was accelerated in elevated temperature in bolt joint, 125℃, 8×10^4cycle (×8)

(3), Fractures appearance of aluminiume alloy has been influenced more by elevated temperature than by room temperature. Figure 14 is one of room temperature tests in stable cracks propagation zone in where fatigue striation is clear and uniform. Figure 15 is one of elevated temperature in stable cracks propagation zone, in where exhibiting serious plastic deformation may indirectly cause distortion of fatigue striation and accompanying oxidation in also where fatigue striation is not clear, ununiform, or edge is not clear.

Observation indicate:

Plasticity was markedly increased in elevated temperature test rusult, in term of microscope, intergranular slip necd energy was decreased in, in addition to intercrystalline welt or enageing are in crease plastic deformation. The more elevated temperature the more plastic deformation is markedly increase and exhibit a lot of climples or tearing edge. Figure 15 shows these effect of elevated temperature on fracture appearance. in order to compare, also shows of these where was effected on fracture appearance by room temperature.

- Figure 16 shows phenomenon of grain slip in that was caused by elevated temperature or local soften.
- Figure 17 shows fractures of fatigue' test for set head revit joint in 150℃. It can be seen that fretting surface was cleanly fragment and elevated temperature cause plastic deformation in contact surface between rivet head and dimp. It is evidence temperature to churn up by the heavy scuffing action and to accelerate action of elevated temperature.
- Figure 18 shows the effect of temperature on fatigue groove preseated wavy situation in crack initiation zone.
- Figure 19 shows the effect of elevated temperature on crack irregularly propagation in where there are small black pit of that Al_2o_3come off remains
- Figure 20 shows stable propagation zone in where the plastic deformation cause fringe smooth
- Figure 21 shows of that plastic deformation under elevated temperature cause not only grain folds and pile up but also grain–boundary become fuzzy.
- Figure 22 shows plastic cracks in where two large grain has evidence plastic deformation.
- Figure 23 shows speed propagation zone in where plastic deformation is serious and doesn't fringe or facet.
- Figure 24 shows shear fracture zone in where there are many tearing fringes or fibrius structure.
- Figure 25 shows fracture appearance of cracks propagation zone in room temperature, in where step evideant to be similar to cleavage character lead to brittle fracture.

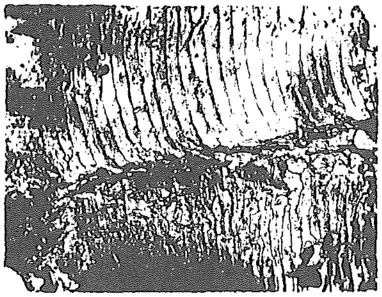

Figure 14 Fatigue striation is clear or uniform, Crack propagated from left to right. Middle is grain borndary. room temperature, (SEM ×4900)

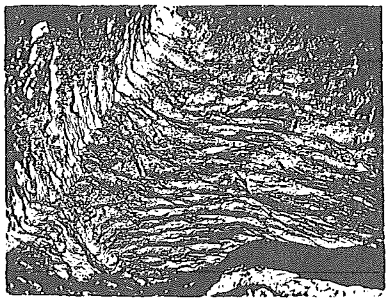

Figure 15 Plastic deformation made striation un–parallel and oxidized point can been seen in upper.LY–12. 200℃ (SEM ×10500)

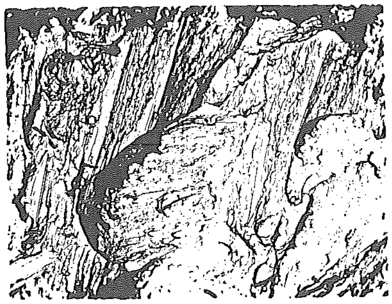

Figure 16 Grain boundary sliping, folds, exhibited local solfening. 150℃, (SEM ×4900)

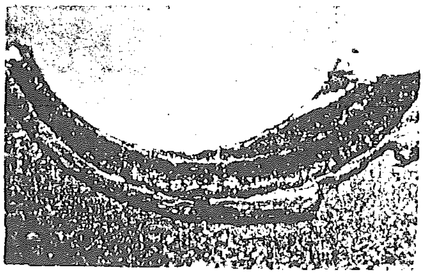

Figure 17 Fretting between in set–head rivet and sheet made a edge of sheet roll up (×12)

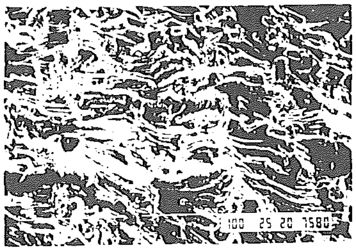

Figure 18 Effect of temperature on fatigue groove made wave situation, in cracks initial zone 100℃ (SEM × 175)

Figure 19 The effect of elevated temperature on crack irregularly propagation in where there are small black pit of that Al_2o_3 come off remains. 200℃ (SEM ×375)

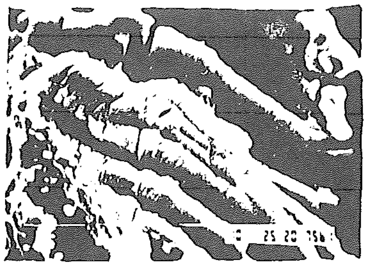

Figure 20 Stable propagation zone plastic deforwation cause fringe smooth. 200℃ (SEM ×1000)

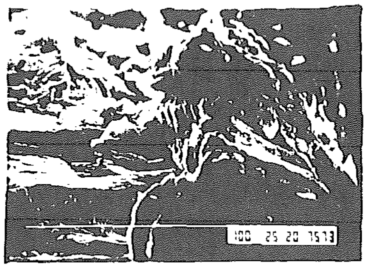

Figure 21 The plastic deformation under elevated temperature cause grain folds. pile up and grain–boundary become fuxxy, 200℃ (SEM ×375)

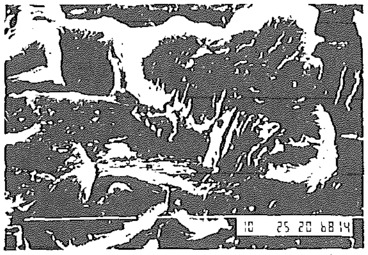

Figure 22 The plastic cracks in where two large grain has evidence plastic deformation and fatigue striations, 150℃ (SEM ×2000)

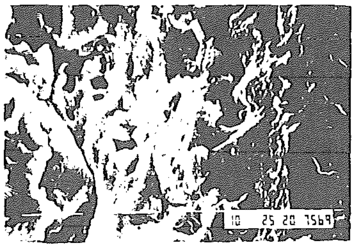

Figure 23 The speed fracture zone, plastic deformation is serious and doesn't fringe or facet 200℃ (SEM ×1000)

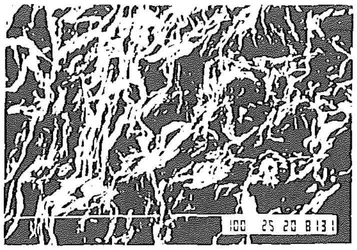

Figure 24 Shear fracture zone, there are many tearing fringes or fibrius structure. 150℃ (SME ×300)

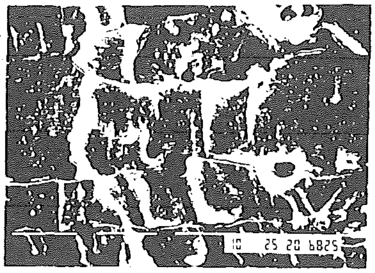

Figure 25 Cracks propagation zone in room temperature. step is evident to be similar to cleavage character lead to brittle fracture. (SEM ×750)

5. Conclutions

By the surveing of above facts about some fracture appearance, it can be clearly seen that elevated temperature fracture is different from room temperature fracture, because of the action of temperature oxidition, plastic deformation, creep and fretting.

1. It can be observed, series character of toughness fracture, dimp, tear fringein in elevated temperature instead of presenting brittle fracture flet of cleavage in room temperature.
2. It can be clearly seen that the fatigue striation not only have been easy found but also have been gone paranlle forward between striation and striation in room temperature. However, in elevated temperature to found fatigue striation is difficult, because It is not clear, sometime confused wave phonomenon of striation in elevavted temperature with beach marks in room temperature.
3. there are many oxideation grain and fuzzy fracture appearance was made by the friction oxidation and the fretting.
4. At elevated temperature some Intergranular preciptation, local soft, melt, intercrystalline folds, elongated and fuzzy phenomenou of fringe are existed.

reference

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