FATIGUE PROPERTIES OF SCS-6/SP700 TITANIUM MATRIX COMPOSITE

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SUMMARY: Isothermal fatigue properties of unidirectional SCS-6 /SP700 (Ti-4.5Al-3V-2Fe-2Mo(wt%)) metal matrix composites (MMCs) were evaluated. The objective in this study is to examine the fatigue properties of SCS-6/SP700, the temperature dependence on its fatigue life and the effect of the fiber exposure at the side edge of the specimen on its fatigue life. Load-controlled high cycle fatigue tests were conducted at RT (293 K), 543 K and 673 K in order to evaluate the isothermal fatigue properties. All data at the different temperature in this study are in relatively narrow range. There is no remarkable effect of fiber exposure on the fatigue life. While microstructures of specimens with and without fiber exposure indicate the difference in fracture mode.

KEYWORDS: Titanium Matrix Composites, SP700, titanium alloy, SCS-6, silicon carbide, high cycle fatigue, fractography, crack initiation

INTRODUCTION

Titanium matrix composites (TMCs) are being considered for structural applications in advanced gas-generator, because of their high strength and stiffness. TMCs, however, have some difficulties for use in gas-generator such as property degradations caused by interfacial reactions during consolidation and secondary fabrication. One of the most attractive solutions is to lower the consolidation temperature that prevent excessive reaction at fiber/matrix interface. There should be two solutions in order to lower the consolidation temperature. One is applying the high formability titanium alloy such as SP700. The other is applying the fiber coating process such as EB-PVD to get the fine matrix structure. In both cases, the consolidation temperature can be lower by about 150 K [1,2]. TMCs consolidated at lower temperature could be expected to have good mechanical properties, because of their less reaction at fiber/matrix interface.

The fatigue properties of TMCs, both unidirectional and cross ply, from room temperature to high temperature, under various loading conditions have been reported [3-11]. But the properties of TMCs consolidated at lower temperature have been rarely reported [1,2]. And the fatigue properties of SCS-6/SP700 have not been reported yet.

Some of the fatigue crack initiations in TMCs are at the specimen corners and edges, because the exposed fibers are damaged during machining [3]. This problem could be solved using the test specimen without fiber exposure at the side edge.

The purposes in this study are to investigate the fatigue properties of SCS-6/SP700 in order to reveal the effect of the lower consolidation temperature on the fatigue property of TMC and to examine the effect of the fiber exposure of the specimen on its fatigue life.

2. EXPERIMENTAL PROCEDURE

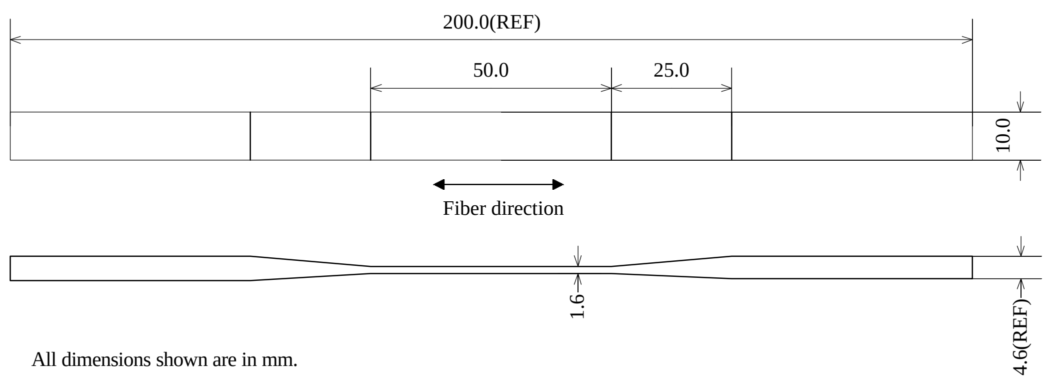
2.1 Composite Materials

The material used in this study was unidirectional aligned continuous SiC fiber-reinforced $\alpha+\beta$ titanium alloys (AMS4899, Ti-4.5Al-3V-2Fe-2Mo(wt%): hereafter denotes SP700). The SiC fiber (SCS-6, produced by Textron Systems, Lowell, MA, USA) has a diameter of 140 μm with 3 μm thick double carbon coating surface layer. The matrix alloy foil, whose nominal thickness was 120 μm, was supplied by NKK Corporation.(Tokyo, JAPAN). The matrix alloy, SP700, shows excellence superplasticity below 1073 K [12,13].

Six fiber layers composite panels were fabricated through foil/fiber/foil consolidation process. The stacked materials, SP700 foils and SCS-6 woven fabrics, were put into a steel capsule and the inside of the capsule was degassed to a vacuum of 10^{-3} Pa at 873 K for 7.2 ks. The hot isostatic pressing (HIP) was done at 1048 K for 7.2 ks under a hydrostatic pressure of 120 MPa. The consolidation temperature was lower by about 150 K than that of other titanium matrix composites.

The test specimen was cut from the SCS-6/SP700 panel with tabs which had been diffusion-bonded during consolidation. The configuration of test specimen of composite was rectangular type as shown in Fig. 1. The volume fraction of fiber (Vf) at the gage section was varied from 34% to 40%.

Test specimen without fiber exposure at the side edge was fabricated from the SP700 foils and SCS-6 woven fabrics in 8 mm width by the same process of the other specimens above. The Vf of the specimen at the gage section was 18% in average, because of the fiber free zone at the edge of the specimen. While the Vf of the referential test specimen with fiber exposure at the gage section was 28%



2.2 Fatigue Test

Load-controlled high cycle isothermal fatigue tests were conducted at RT (293K) and 673 K with an R ratio (minimum stress/maximum stress) of 0.1 and a test frequency of 10 Hz using a Shimadzu Servopulser (EHF-EA5). Fatigue tests at 543 K were conducted with the same test conditions described above using the specimens with and without fiber exposure at the side edge of the specimen. All tests were performed in the atmosphere.

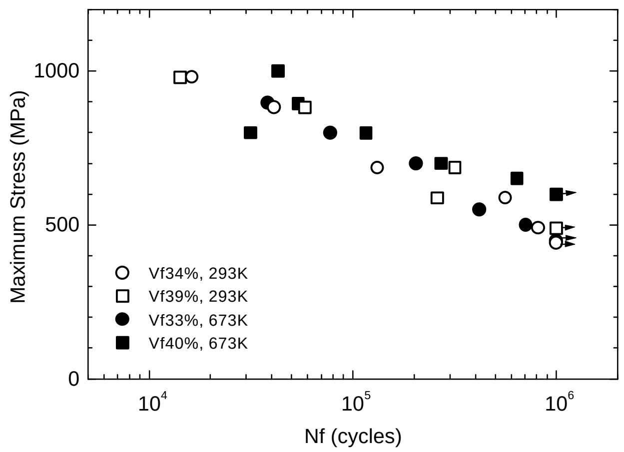
Microstructures and fracture surfaces of the specimens fatigued to failure at 543 K were examined.

3. RESULTS AND DISCUSSION

3.1 Fatigue life

The fatigue lives of SCS-6/SP700 at 293 K and 673 K are plotted as a function of maximum stress in Fig. 2. All lives were within a relatively narrow band in spite of the difference of the test temperature and Vf, while there were some scatters in the same test condition. In other words, there was no apparent temperature dependence between 293 K and 673 K. The reason might be that more ductile matrix and weaker interfacial bonding at higher temperature blunt the crack tip easily to prevent crack propagation resulting in longer fatigue life and the residual tensile stress in the matrix during the consolidation is released during elevated temperature fatigue so as to balance with the decrease of the matrix strength at elevated temperature.

Fig.2. Fatigue life of SCS-6/SP700 at 293 K and 673 K



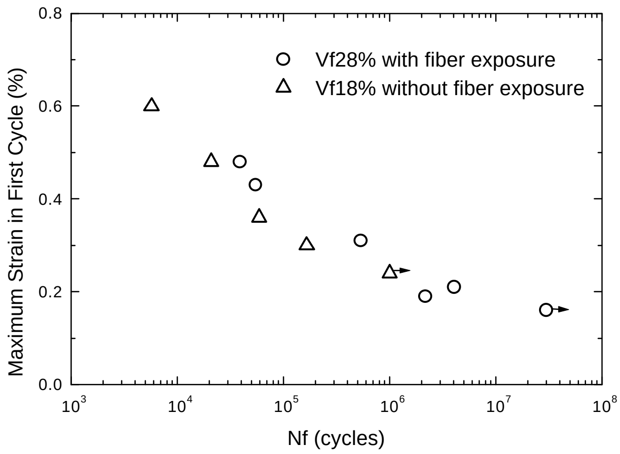


Fig.3. Strain basis fatigue life of SCS-6/SP700 with and without fiber exposure at 543K

Fatigue lives of SCS-6/SP700 without fiber exposure comparing with the lives with fiber exposure at 543K are shown in Fig. 3. In order to reduce the Vf effect, the data were plotted on a strain basis. There seems no apparent effect of fiber exposure on fatigue life.

3.2 Microstructures and fractographs

Some studies have shown that fiber failure is dominated under higher strain range and fiber-bridged matrix cracking is dominated under intermediate strain range in titanium matrix composites as shown in Fig. 4 [5,6]. Microstructure with fiber exposure under intermediate strain shows fiber-bridged matrix cracking as shown in Fig. 5a. While, microstructure without fiber exposure under intermediate strain shows multiple fiber failure as shown in Fig. 5b.

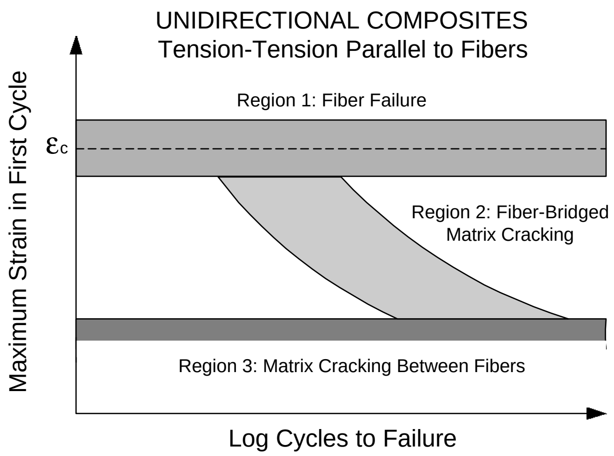


Fig. 4. Failure life diagram of a unidirectional composite loaded in cyclic tension parallel to fibers by Talreja [6]

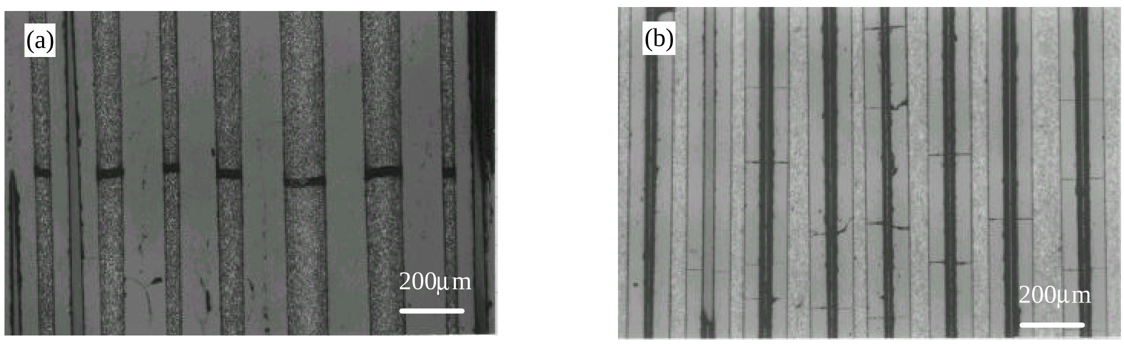


Fig.5. Microstructures of specimens at 543 K (a) with fiber exposure, Nf = 5.37×10^5 cycles at σ_{max} = 572 MPa (ε_{max} = 0.31%) and, (b) without fiber exposure, Nf = 5.92×10^4 cycles at σ_{max} = 588 MPa (ε_{max} = 0.36%).

Typical fractographs of the specimens with and without fiber exposure are shown in Figs. 6 - 8. The large steps were observed on the fracture surfaces in Fig. 6a, 7a and 7b. The steps indicates that the fiber-bridged matrix cracking occurred in the specimens with fiber exposure. Most of the crack initiation were at the surface of the specimen as shown Fig. 6b and 7c. Main cracks were propagated from the surface to the fibers and the final fracture matrix area shows dimple pattern. In the specimen with fiber exposure, the surface initiated failure with fiber-bridged matrix cracking was observed in all stress range in this study at 543 K.

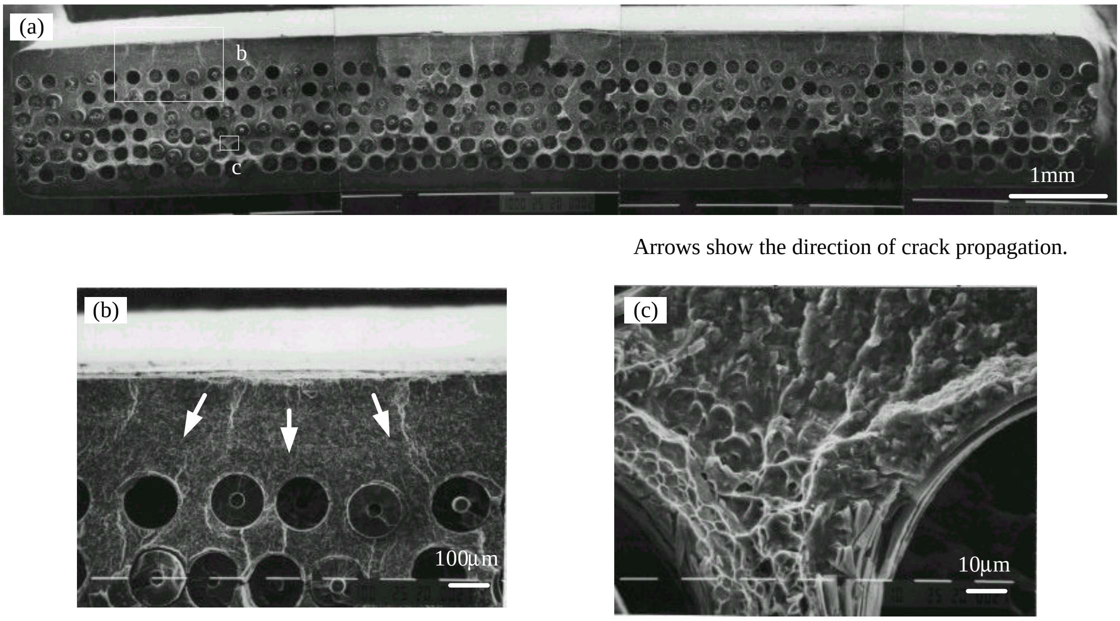


Fig. 6. Fracture surface of the specimen with fiber exposure (T =543 K, Nf = 3.92×10^4 cycles at σ_{max} = 885 MPa), (a) macrostructure, (b) crack propagation from the surface, (c) dimple pattern around fibers

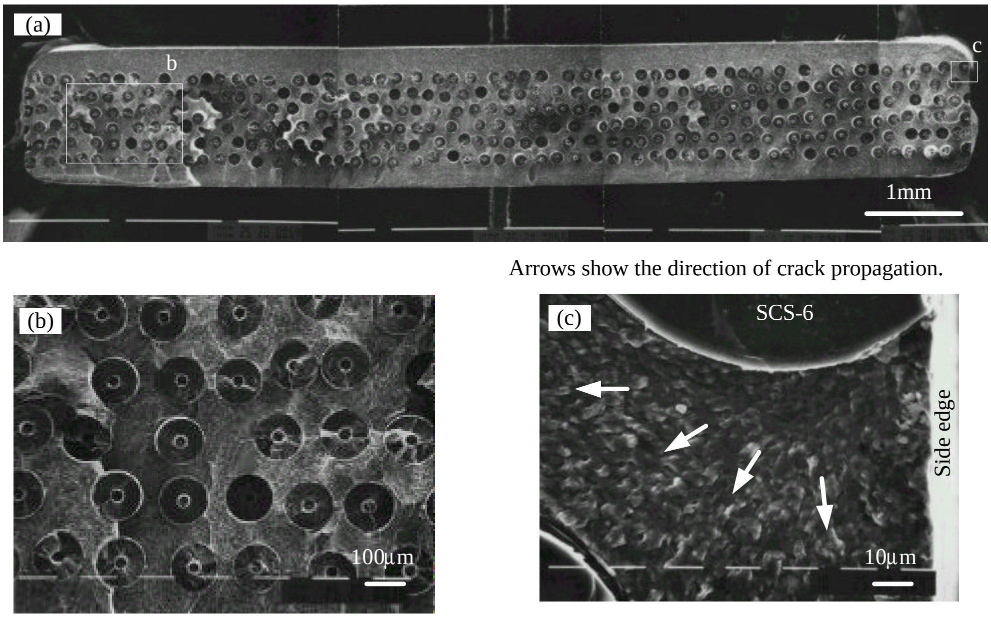


Fig. 7. Fracture surface of the specimen with fiber exposure (T =543 K, Nf = 5.37×10^5 cycles at σ_{max} = 572 MPa), (a) macrostructure, (b) fracture steps, (c) crack propagation from side edge.

The crack initiation in the specimen without fiber exposure was at the surface of the fiber free area as shown in Fig. 8a. The striation in the fiber free area in Fig. 8c shows that the crack was propagated from the fiber free area to the fiber area. There is no apparent sign of steps in the matrix caused by multiple matrix cracking. In the specimen without fiber exposure, the surface initiated failure with multiple fiber failure was observed in all stress range in this study at 543 K. In both of the specimens with and without fiber exposure, the fragile nature of the matrix surface layer may be afraid to be caused by environmental embrittlement.

In load controlled fatigue test, the peak strain increases during the test. Gayda et al. have reported that the greater increase in peak strain was observed in the composite with the lower fiber content [4]. This phenomenon is produced by stress relaxation of the matrix which causes a simultaneous increase in fiber stress and composite strain. The low Vf specimen without fiber exposure causes matrix relaxation and increase in the fiber stress. In addition, the first step of the fracture occurred in the fiber free area of the specimen without fiber exposure. After the crack propagation in the fiber free area, the fiber stress increased because of the reduction of the cross section area in the matrix. Therefore, actual stress range in the low Vf specimen without fiber exposure increased during elevated temperature fatigue test resulting in multiple fiber failure even under initial intermediate stress range.

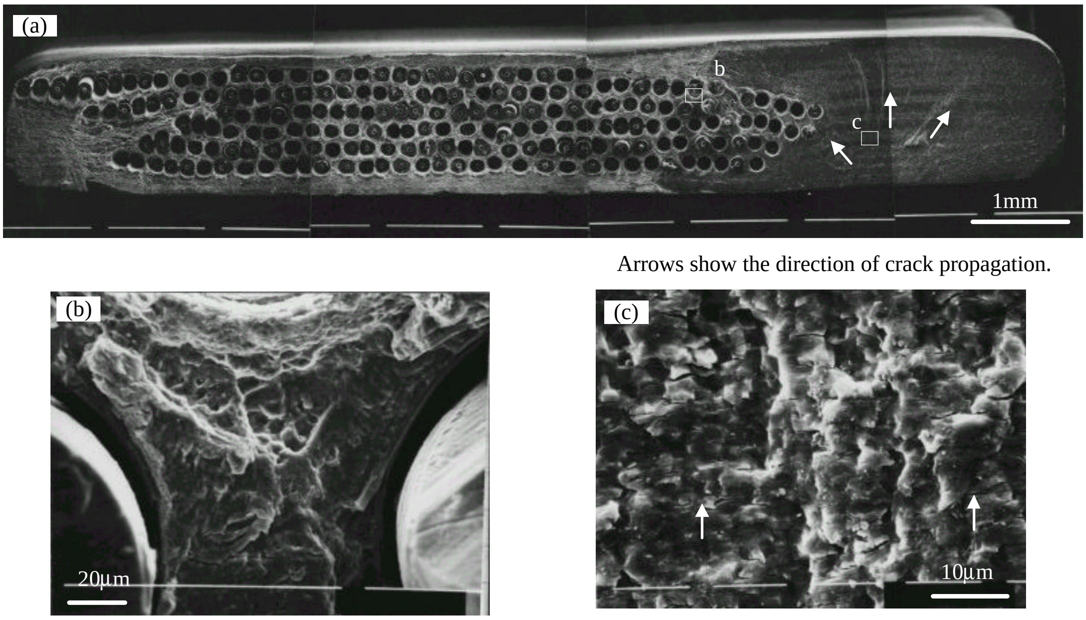


Fig. 8. Fracture surface of the specimen without fiber exposure (T =543 K, Nf = 5.92×10^4 cycles at σ_{max} = 588 MPa), (a) macrostructure, (b) dimple pattern around fibers, (c) striation.

3.3 Fatigue life comparison

Fatigue life comparison between SCS-6/SP700 and SCS-6/Ti-15-3 at room temperature and that at elevated temperature are summarized in Fig.9 and 10 respectively.

The consolidation temperature of SCS-6/SP700 is lower by 150K than those of other conventional titanium alloy matrix composites. The lower consolidation temperature prevents the excessive interfacial reaction. Some reports show that most of the fatigue fracture in TMCs occurred at the interfacial reaction products or at the crossing metal ribbon which is an element in SCS-6 woven fabrics [5,8]. SCS-6/SP700 has less reaction layer, 0.4µm, than other conventional TMCs, 0.7-0.8 µm [14,15]. Consequently, SCS-6/SP700 could be expected to have better fatigue properties. However, Fig.9 and 10 show no apparent superiority of SCS-6/SP700 in fatigue life. One of the reasons is that most of the crack were initiated at the surface of the specimen not at the fiber/matrix interface. Therefore the less reaction layer in SCS-6/SP700 could not result in the improvement of the fatigue life.

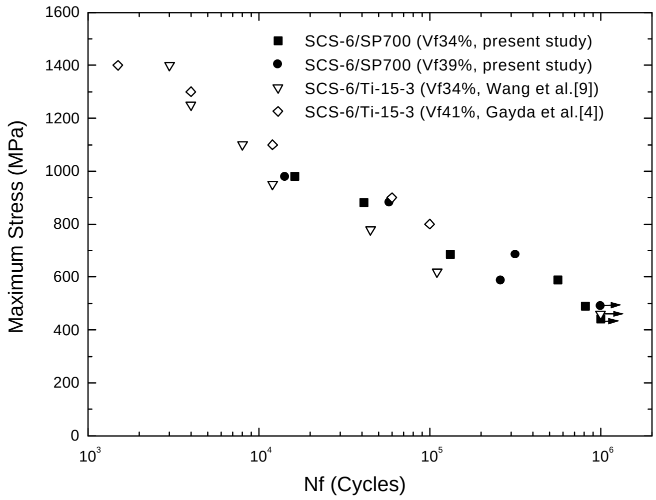


Fig.9. Fatigue life of TMCs at room temperature

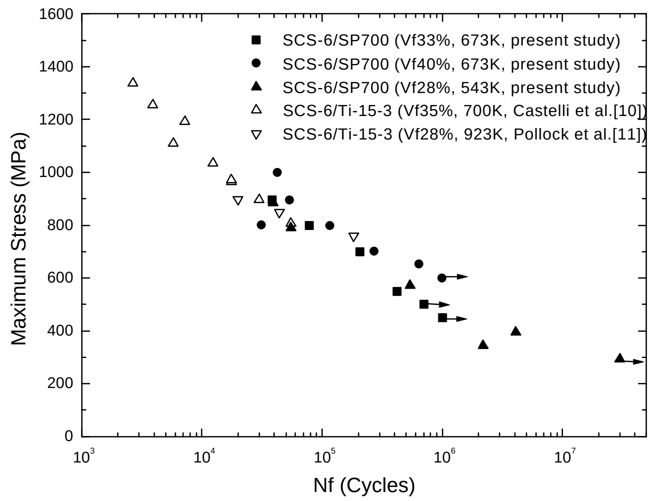


Fig.10. Fatigue life of TMCs at elevated temperature

4. CONCLUSIONS

Load-controlled high cycle isothermal fatigue properties of SCS-6/SP700 and the effect of the fiber exposure of the specimen on its fatigue life were investigated. The following results were obtained:

1. The fatigue life of SCS-6/SP700 was similar to other titanium matrix composites, such as SCS-6/Ti-15-3.
2. No apparent temperature dependence from 293 K to 673 K in fatigue life of SCS-6/SP700 was observed.
3. No apparent differences in fatigue lives at 543K between the specimen with fiber exposure and without fiber exposure were observed in spite of the difference of the fracture mechanism.

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