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Coupling characteristics of the spun optical fiber with triple stress elements

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ABSTRACT

An empirical formula related to the stress field distribution in the optical fiber with triple stress elements is proposed and proved. The possible intercoupling between the fundamental modes and the higher order modes is demonstrated. The transmission property of the spun optical fiber with triple stress elements is analyzed. The experimental data from a sample of the spun optical fiber with triple stress elements confirm the theoretical results very well.

1. Introduction

It is well known that an optical fiber with double stress elements placed symmetrically on the both sides of the core has linear birefringence [1–19], such as the Bow-Tie optical fiber, Panda optical fiber and etc. This linear birefringence arises from the stress field distribution difference along the major-axis direction and the minor-axis direction. When we consider about an optical fiber with triple stress elements which are placed symmetrically around the core, what will happen? First of all, by intuitive deduction, there should be no linear birefringence because the three stress elements are placed symmetrically and there is no any special direction in which the light can be linearly polarized. In fact, the stress field is very complicated. There are not only the normal stress components but also the shear stress components in the stress tensor [20]. The stress tensor and the related main stress direction are different with points to points on the cross section of the optical fiber. In this paper, the stress field distribution will be analyzed by some numerical simulation. An effective empirical formula about the stress tensor of the optical fiber with triple stress elements will be present. The coupling characteristics between the fundamental modes and the higher order modes and the transmission property of the spun optical fiber with triple stress elements will be studied.

2. Empirical formula for the stress tensor with triple stress elements

To draw effective conclusion from the stress field distribution, a typical optical fiber with triple rectangular stress elements is considered here. As is shown by Fig. 1, three doped rectangular stress elements in the cladding are distributed symmetrically around the core of the optical fiber. To calculate the stress field distribution or the two dimensional stress tensor $\tilde{\sigma}_{xy} = \begin{bmatrix} \sigma_x & \tau_{xy} \\ \tau_{yx} & \sigma_y \end{bmatrix}$ on the cross section of the optical fiber, the Comsol Multiphysics software is employed.

The related parameters of the optical fiber with triple rectangular stress elements are shown in Table 1, where a and b represent the length and width of the stress element, d represents the distance from the doped stress element center to the fiber core center and c represents the fiber core radius. α_{core}, α_{clad} and α_{sap} represent the corresponding expansion coefficients in the core, cladding and the doped elements. E and υ are the Young's modulus and Poisson ratio related to the elasticity. $\Delta T = T_{cool} - T_{hot}$ is the temperature difference between the cooled fiber room temperature and the melted fiber hot temperature in the optical fiber drawing process.

First of all, the distribution of the normal stress average $\bar{\sigma} = (\sigma_x + \sigma_y)/2$ is shown in Fig. 2. From this figure it can be seen that the normal stress average $\bar{\sigma}$ is almost a constant on the whole cross section of the optical fiber core, which is designated by the small circle. Because the normal stress average is independent of the reference coordinates which are elected to express the components of the stress tensor and it will not affect the coupling characteristics of the optical fiber, it will be ignored in the most part of the following discussion.

In Fig. 3a, the distribution of the half normal stress difference $\delta\sigma/2 = (\sigma_y - \sigma_x)/2$ calculated by the Comsol Multiphysics software is demonstrated. In Fig. 3b, the corresponding results are shown specifically along a circle whose radius is half of the fiber core radius, e.g. the distance from the circle to the fiber core center is $r = c/2 = 2$ μm. In Fig. 4a, the distribution of the shear stress $\tau_{xy} = \tau_{yx}$ calculated by the Comsol Multiphysics software is also demonstrated. In Fig. 4b, the

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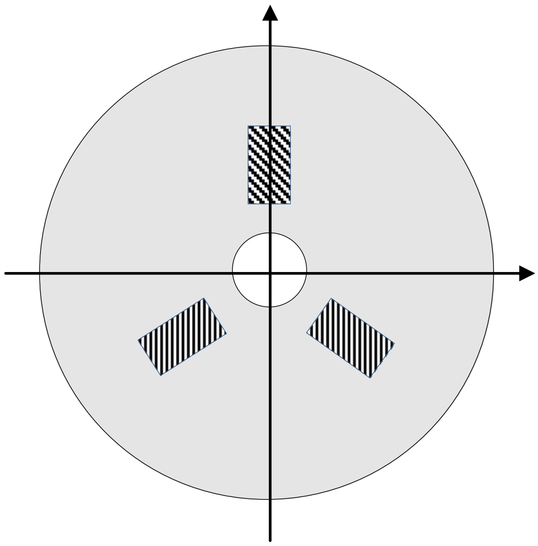

Fig. 1. Optical fiber with triple rectangular stress elements.

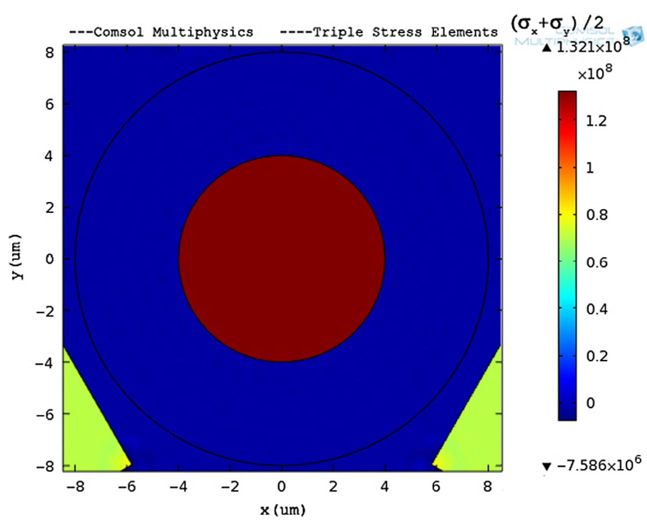

Fig. 2. Normal stress average $\bar{\sigma}$ distribution in the optical fiber with triple rectangular stress elements, which is calculated by Comsol Multiphysics.

Table 1
Parameters of the optical fiber with triple rectangular stress elements.

Parameter	E (10^{10} N/m^2)	ΔC (10^{-12} m^2/N)	υ	R (μm)
Value	7.8	3.43	0.186	62.5
Parameter	α_{core} (10^{-6} °C^{-1})	α_{clad} (10^{-6} °C^{-1})	α_{sap} (10^{-6} °C^{-1})	ΔT (°C)
Value	2.215	0.54	1.45	1680
Parameter	a (μm)	b (μm)	d (μm)	c (μm)
Value	16	8	17	4

corresponding results along the same circle whose radius is half of the fiber core radius are shown too.

From the curve of Figs. 3b and 4b it can be seen that the half normal stress difference $\delta\sigma/2$ complies with the sine curve while the shear stress τ_{xy} complies with the cosine curve and their amplitude are equal to each other. So the stress tensor may be written as follows:

$$\tilde{\sigma}_{xy} = \begin{bmatrix} \sigma_x & \tau_{xy} \\ \tau_{yx} & \sigma_y \end{bmatrix} = \begin{bmatrix} \bar{\sigma} + \delta\sigma/2 & \tau_{xy} \\ \tau_{yx} & \bar{\sigma} - \delta\sigma/2 \end{bmatrix}$$

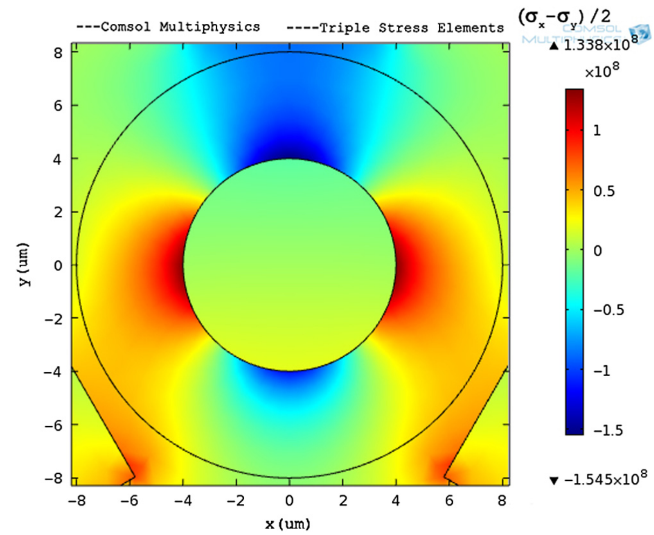

Fig. 3a. Half normal stress difference $\delta\sigma/2$ distribution in the optical fiber with triple rectangular stress elements, which is calculated by Comsol Multiphysics.

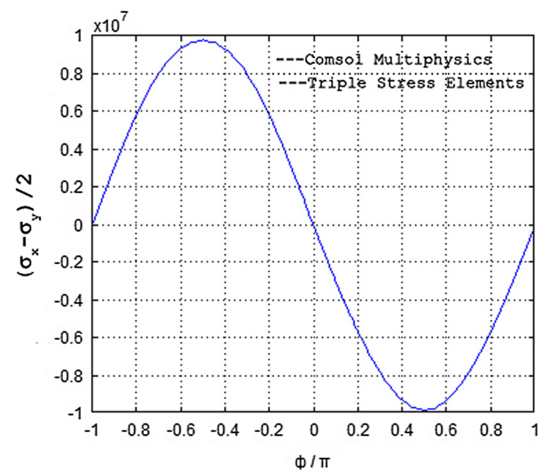

Fig. 3b. Half normal stress difference $\delta\sigma/2$ line diagram in the optical fiber with triple rectangular stress elements, which is calculated by Comsol Multiphysics.

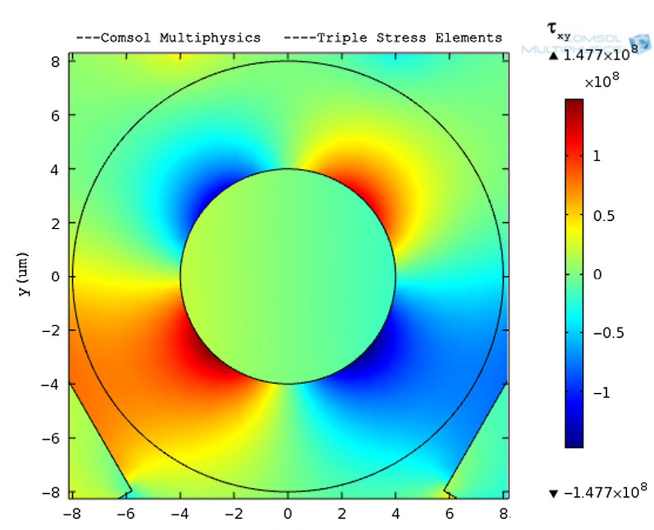

Fig. 4a. Shear stress τ_{xy} distribution in the optical fiber with triple rectangular stress elements, which is calculated by Comsol Multiphysics.