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CHARACTERIZATIONS ON BENDING EFFECT ON CUSTOMIZED SPLITTERS USING VARIOUS RADII OF ELLIPTICAL-SHAPED BLOCKS

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Abstract

Macro-bending effect unto polymer optical fiber (POF) based splitters study is done to analyse the performance and characterizations using several bending radii of geometrical blocks that hold a customized prepared polymer fiber splitter. A pair of etched fibers with similar core diameters are attached to the ellipse-shaped blocks built using matching refractive index material where the blocks were built with various bending radii. The tapered fibers were lapped closely with some forces exerted upon them in order to stimulate the splitting of modes between the two fibers. This study is done by experimental set-up where each of the splitter ports is connected with optical power meter to measure the power output while pressure is exerted. Characterization is executed in order to investigate and analyse which bending radius gives the most optimize splitting ratio with considerable low loss for the particular splitter prepared. As for normal force of 0.3 lbF, the optimum splitting ratio with low loss is specified having bending radius, Rc, of 13 mm whilst for external force of 3.0 lbF, bending radius is found to be 19 mm. Small bending radius stimulates the radiation of rays into the second fiber while larger Rc gives longer coupling length that optimize the splitting ratios. Efficiencies between simulated values and experimental values are also analysed.

Keywords: Macro-bending, Splitters, Geometrical blocks, Bending radius.

1. Introduction

Polymer optical fiber is widely used as an effective medium in short-haul communication system. One of the important components used in short distance communication system is splitters. Known methods used to develop splitters are fused technique as shown by [1], Y-splitter [2], side-polishing, chemical etching, thermal deformation, molding and splitter developed by industries that gives high performance [3]. This study aims to develop user-friendly and inexpensive splitters with low excess loss using POF splitter kit consists of different bending radii and several pairs of splitters.

This device is described as user-friendly since the various blocks having different bending radius will allow different amount of rays to couple to the second fiber therefore the splitter will give various splitting ratios instead just one splitting ratios as conventional splitter does and giving the users the option to set the demanded splitting ratios. Thus, this technique of splitter development [4] has the advantage of low-cost installation, environmental-friendly [5] with considerable low losses. There have been studies on bent losses [6-7], however, this study covers bigger bending radius since we use ellipse-shape blocks for the splitters. Ab-Rahman et al. [4] shows the study of etching process done unto the splitter which is important since the etching process duration affect the thickness of the core-cladding thickness, while in the other hand, Durana et al. [6] shows that bending effect of larger angle is unappreciated as compared to smaller bending radius. However, the study did not show the effect of power output of a splitter. While Musa et al. [7] shows the bending is independent of wavelength, they also show that as the bending radius is larger, the transmission of modes decreases using ray optics simulation. However, the study does not show experimental results or using circular fiber as shown in this study since the study [7] focus on planar waveguide.

In this study, two strands of POF were etched beforehand for about 25 mm long. The etching process duration was one hour to two hours long using harmless chemical solvent; acetone. The purpose of this etching process is to strip off cladding layers so when the fibers are lapped to each other, the modes that travel from the first fiber can be transferred to the second fiber. However, due to the etching process that eliminates the whole cladding layers around the fibers including the regions that will not be lapped, geometrical blocks that are built to hold these fibers were carved with grooves around the edges and the material that is used to build the blocks was acrylic, which has the same refractive index matching as the cladding layers. Thus, it will assist to prevent the modes from radiated out to the air and causes excessive losses. This particular splitters will be attached to different ellipse-shaped blocks each with different bending radii to analyse the effect of macro-bending unto the developed splitter with core diameter between 0.75 mm-0.85 mm and etching length of 25 mm long with two external forces exerted upon the splitters, namely, normal force and given force.

Force is used in this study in order to minimize the air gap that existed between the lapped fibers. The combination of the parameters is aimed to observe the best bending radius that give optimum splitting ratio and low excess loss for the particular splitter. The overall objective of this study is to analyse the bending effect of the particular splitter having similar core radius that was lapped in the middle and attached to different bending radius of elliptical-shaped blocks. Since bending of fibers or splitters affect the propagation of rays in the waveguide therefore this study shows the behaviour of the splitting ratios, excess losses and insertion losses of the splitter developed using lapping technique having varied bending radii.

2. Experimental Setup

Experimental procedure is shown in Fig. 1 where the flowchart briefly shows the process of the splitter characterized using different bending radii. A customized platform as shown in Fig. 2 and ellipse-shaped blocks are built using refractive index matching materials, i.e., acrylic that has similar refractive index of cladding, 1.459. The reason is to replace the etched cladding layers so that the modes radiated from the first fiber can be prevented from radiated out to the air, thus, it will be reflected back to the cores. The shapes of the blocks are similar, however, only the radius of the bending varied with 10 mm, 13 mm, 16 mm, 19 mm, 22 mm, 25 mm and 28 mm particularly.

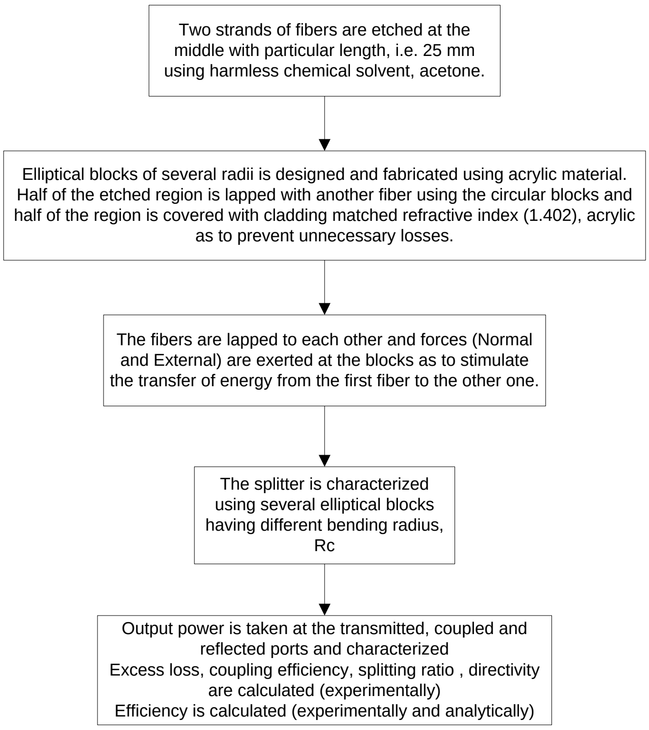

Fig. 1. Flowchart of Experimental Procedure.

POF fiber of 30 cm length is etched in the middle area with etching length of 25 mm. The diameter of the cores after an hour of etching is between 0.75 mm-0.85 mm. At this diameter, the cladding layers have been etched fully which left only the cores at the particular area. The pair of POF strands are placed at the middle groove of the ellipse-shaped blocks.

When lapped together, two forces were imposed onto the blocks at the other end of the groove, particularly, normal force, Fn of 0.3 lbF and given force, Fc of

3 lbF. The force is imposed on the blocks therefore also the coupling regions between the two etched area. Normal force is assumed as the normal stress existed between the two fibers when touching while no excess pressure existed. Thus, air gap between the two fibers is assumed to exist.

Source of 650 nm red light is injected into input port, P1 and went through coupled port, P3, throughput port, P2 and reflected port, P4. Throughput port, P2 is the port where the rays from the source propagate directly under the same waveguide while coupled port, P3, is the port where the rays are coupled into when the core of the propagated rays is lapped to the other core and the rays are transferred to the second core and propagate along the new waveguide. Reflected port, P4, in the other hand is the port where the propagating rays that flow from the first fiber to the second fiber went under some reflection to the P4 port instead of propagating through coupled port, P3. The values of all output power at all the ports are recorded accordingly.

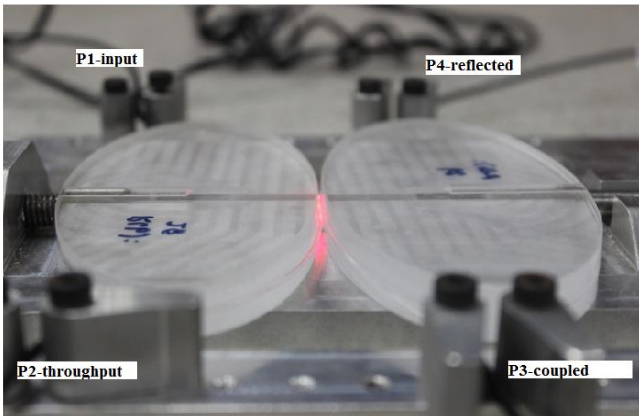

Fig. 2. Customized Splitter using Ellipical-shaped Blocks and Various Radii.

Force gauge as shown in Fig. 3 is used to exert pressure intended unto the blocks and the fibers. Different bending radius were used for the particular splitters to observe and analyse the characteristics and behavior of the splitter when different bending were applied unto the fibers with the existence of normal force and given force. Bending radius or macro-bending is known to have stimulated the radiation of modes from one fiber to another.

Fig. 3. Force Gauge used to Exert Pressure onto the Splitter.

3. Results and Discussions

Figure 4 shows the data collected from the force gauge where normal force was imposed onto the splitters with average value of 0.3 lbF. Figure 5 in the other hand shows the average force of 3.0 lbF when the gauge exerted onto the blocks for few seconds. During the force exertion, readings of output power at coupled port, throughput port and reflected port were recorded.

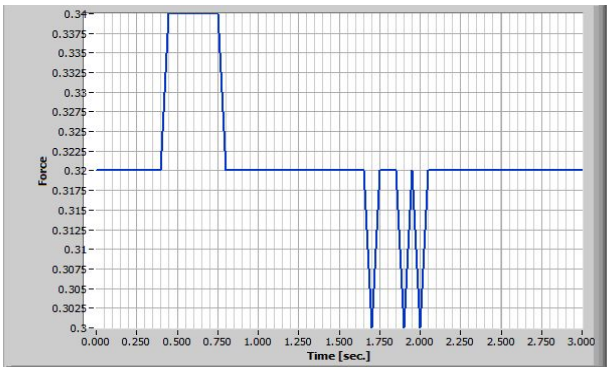

Fig. 4. Pressure of Fg of 3 lbF is Exerted upon the Splitters.

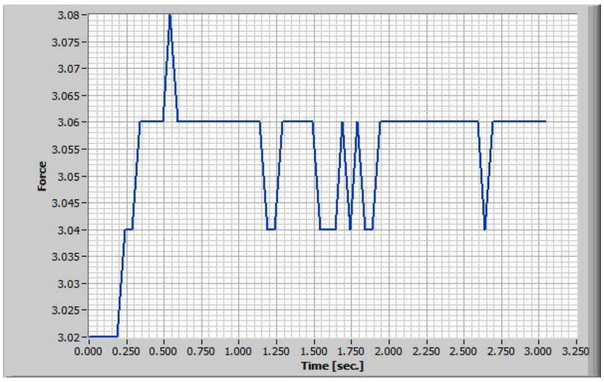

Fig. 5. Normal Force, Fn of 0.3 lbF is Exerted on the Splitter.

When the pair of splitter is attached to different bending radius blocks of radii 10 mm, 13 mm, 16 mm, 19 mm, 22 mm, 25 mm and 28 mm, different values of output powers were obtained. Characterizations on each of the bending radii were analysed with the existence of different forces. As shown in Fig. 6. to Fig. 12., the Rc is the radius of the blocks respectively as mentioned above. Figure 6 shows the splitting ratio of coupled port for all the bending radii at normal force and given force.

As shown in the figure, the splitting ratio of the given force shows higher percentage compared to the normal force. This is due to the small existence of gap between the fibers compared to the small force of 0.3 lbF that gives lower splitting ratio due to the air gap between the fibers. This in particular prevented the propagation of modes being transferred from the first fiber to the second one. From the data shown, we can see that at normal force, the bigger the bending radii, the lower the splitting ratio.

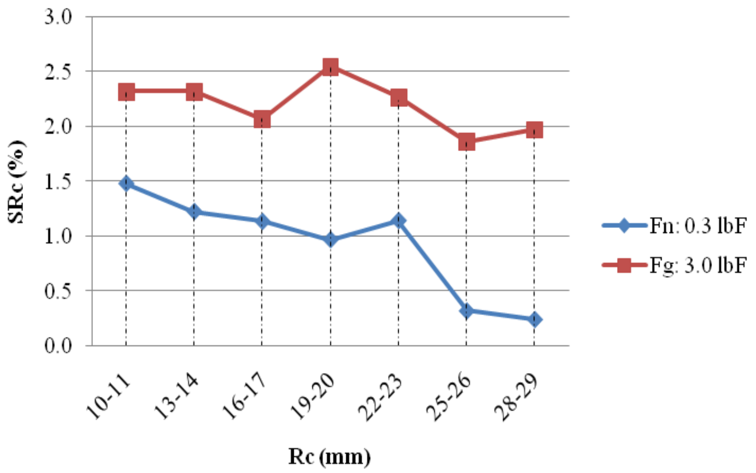

Fig. 6. Splitting Ratio of Coupled Port for each of the Bending Radii at Normal Force and Given Force.

However, when the force is bigger, the splitting ratio difference is smaller when the bending radii increases from 10 mm to 28 mm. When normal force was imposed, bending radius of 10 mm shows the highest splitting ratio and bending radius of 28 mm shows the lowest splitting ratio. The bending radius of 4 mm shows more critical bending rather than other bending radius, thus, more modes radiated out from the first fiber to the second fiber. As the bending radius gets bigger, low critical bending was imposed and less modes propagate out from the first fiber to the second fiber due to the small stimulation of bending factor.

However, in the case of higher force exertion, the air gap existed has cease and the fibers were close in proximity. Thus when the bending radius is small, i.e., 10 mm, 13 mm and 16 mm, the critical bending stimulates more modes to transfer from first fiber to the second one. However, when the bending radius gets bigger, i.e., 19 mm, 22 mm, 25 mm and 28 mm, and less critical, bending ceases to become the factor of mode transferring between the fibers, rather the small gap between them counts as the factor that encourage the modes to propagate to the second fiber. The given force has closed the gap and makes the fibers closed in proximity thus, the percentage of modes propagate to the other fiber is higher than when the gap is bigger. Thus, the difference of splitting ratio when the bending is 10 mm has small different when the bending is 28 mm.

Nonetheless, the bending plays important performance parameter since although the gap is closed, small bending radius gives the highest splitting ratio. As can be observed, the splitting ratio is small overall, this is due to the other factor that results the small coupling between the fibers. The diameter of the cores and 25 mm of etching length is quite long for this developed splitter. The region that is not lapped to each other exposes the bared core area and most of the rays that travelled along the bare area gets lost into the air. Thus, fewer modes were transferred to the other fiber.

Figure 7 shows the splitting ratio at the throughput port. Splitting ratio of the normal force is higher for all the bending radius compared to the splitting ratio of the given force. More modes stay at the first fiber rather than transferred to the other fiber when normal force is imposed. From the figure, as the bending radius gets bigger and flatter, the splitting ratio at throughput port is higher. Again due to the critical bending radius of small bending, i.e., 10 mm, 13 mm and 16 mm, the modes get radiated from the first fiber to the second fiber more than when the bending radius is less critical and bigger. Thus, the rays stay at the throughput port when there is no stimulation factor that helps the modes to propagate to the other fiber.

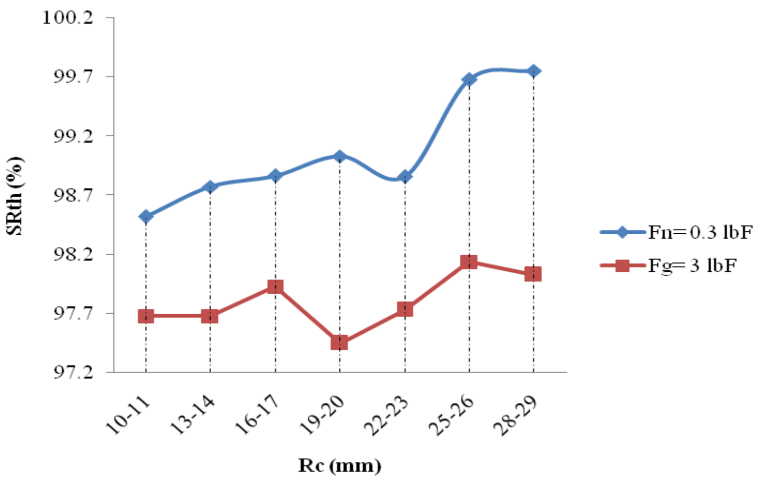

Fig. 7. Splitting Ratio at Throughput Port.

As for the given force, when the gap is closed and the fibers are closed in proximity, although the bending radius gets bigger, the less existence of gap between the fibers help the modes to get transferred from the first fiber to the second one. Thus, lower percentage of rays propagate in the throughput port. However, for small bending radius, more modes get transferred to the second fiber due to the radiation of the bending factor.

Figure 8 shows the excess loss for the developed splitter. The excess loss shows small significant different when the bending radius get bigger for both normal force and given force. For normal force, for most of the bending radii, low excess loss was obtained due to less modes get transferred from the first fiber to the second fiber. When the gap is closed, at the small bending radius, excess loss is bit higher due to the critical bending of the fiber. The length of the bare core area is also a factor that contributes to the loss. When bending is less critical, less radiation stimulates the propagation of modes from the first fiber to the second one, thus, lower the loss.

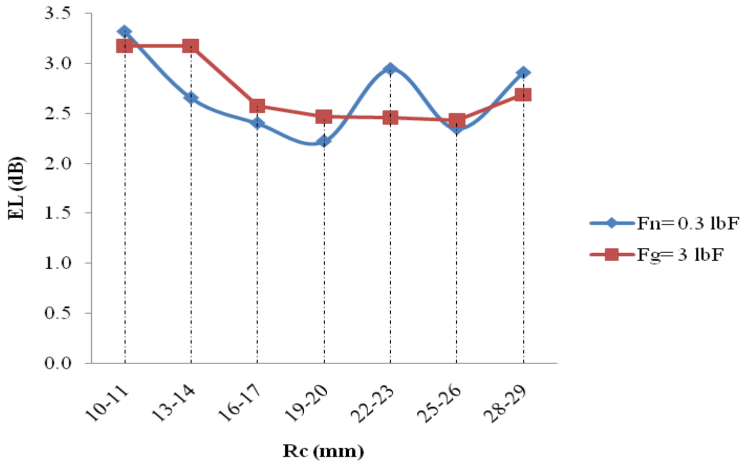

Fig. 8. Excess Loss for the Splitter at Each of the Bending Radii at Normal and Given Force.

In Fig. 9 and Fig. 10, insertion loss at the throughput port shows similar characteristics as the excess loss, thus, similar factor that contributes to the loss. Insertion loss at the coupled port in the other hand where for normal force it is higher than the given force which is due to the gap that existed between the fibers. Most of the loss is contributed to the length of the etching area that is not lapped to the other fiber. For given force, the loss is quite similar for all the bending radii. Therefore, bending radius has small impact onto insertion loss.

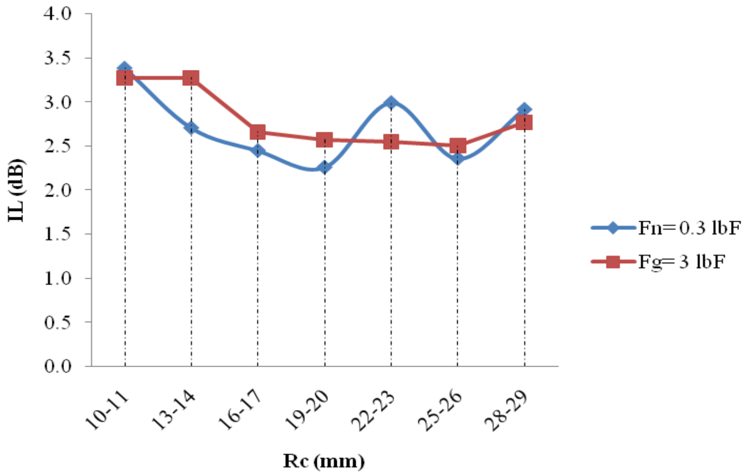

Fig. 9. Insertion loss at Throughput Port for the Splitter at Each of the Bending Radii at Normal and Given Force.

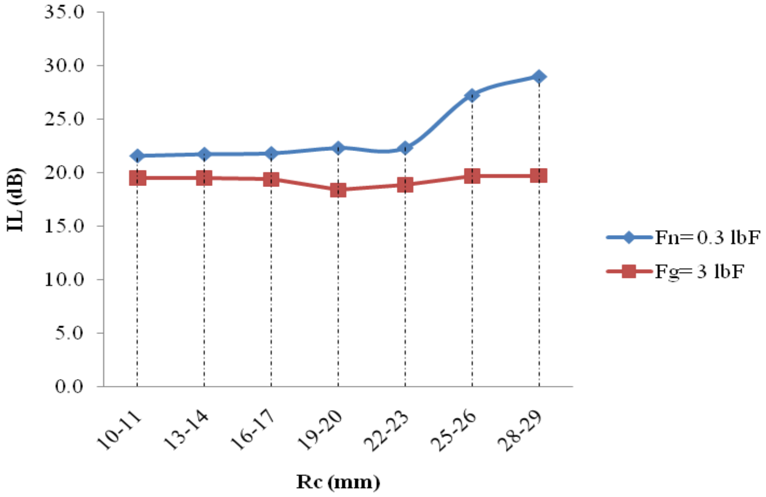

Fig. 10. Insertion loss at Coupled Port for the Splitter at Each of the Bending Radii at Normal and Given Force.

Figure 11 shows the directivity at the reflected port where directivity of the given force is higher than directivity of normal force. When the bending radius gets bigger, directivity decreases. Higher loss is observed when small bending radius is used in the platform. This is due to the more rays or modes that get transferred from first fiber to the second fiber. Thus the directivity at the reflected port is higher. However, when the bending radius is biggest, the directivity increases. This is because the coupling length between the fiber is longer and more rays are reflected at the particular port.

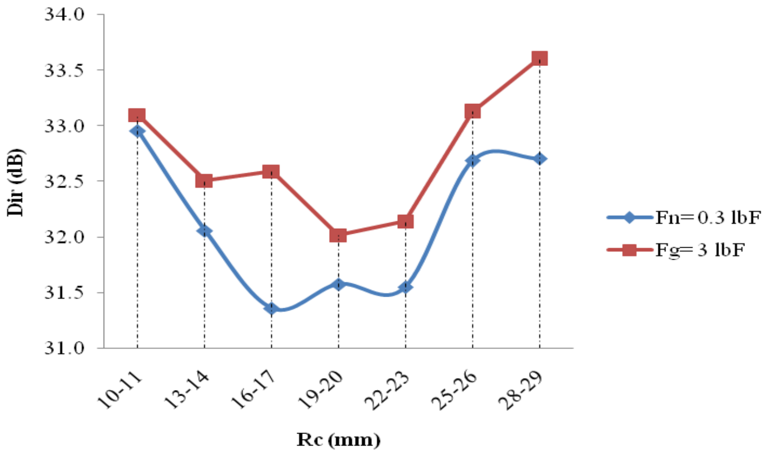

Fig. 11. Directivity at Coupled Port for the Splitter at Each of the Bending Radii at Normal and Given Force.

Figure 12 shows the splitting loss at the coupled ports for each bending radius at both normal and given forces. Splitting loss at bigger bending radius is higher due to the low splitting ratio of the modes. More modes were propagating to the second fiber when bending radii is smaller. Less splitting loss is observed when force of 3.0 lbF is imposed unto the splitters compared to the normal force since the air gap prevents the modes to be mostly propagates along the second fiber. However, by analyzing the profile, the splitting loss shows consistent loss when given force is imposed when bending radii varies due to the small variation of splitting ratio when the bending radii get bigger.

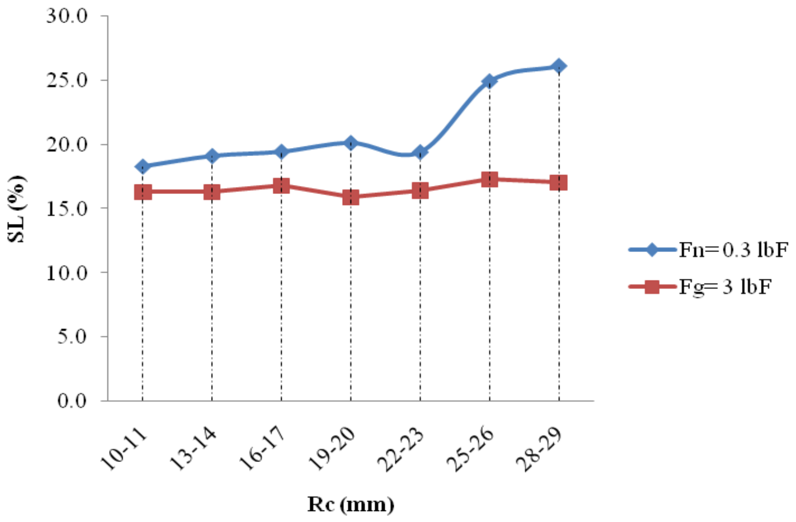

Fig. 12. Splitting Loss at Coupled Port for the Splitter at Each of the Bending Radii at Normal and Given Force.

4. Comparison of Efficiency between MathCAD Simulation and Experimental

The efficiencies of the splitter are compared to simulated efficiency of two lapping fibers having different coupling length, Lc according to the bending radius, Rc of the elliptical blocks. Coupling efficiency obtained by Coupled Mode Theory (CMT) by Ogawa [8] is integrated with Hertz's Law of elliptical point contact which shows in the Eq. (1) below:

$$\eta = \int_0^1 \sin\left[\left(\frac{1}{\sqrt{\pi}}\frac{\sqrt{\mathrm{NA}(n0,n1)}}{\sqrt{k(\lambda)\cdot(a)\cdot(n0)}}\right)\left(\frac{(t)\cdot(1-t)^{1/4}}{a}\right)(2\cdot C)\cdot[1]\right]^2 dt \qquad (1)$$

Simplified CMT [8] shows that the longer the coupling length, the higher the coupling efficiency and the values of efficiencies in this study are plotted as in Fig. 13 for each coupling length. The coupling length, Lc for each bending radius, Rc of 10 mm, 13 mm, 16 mm, 19 mm, 22 mm, 25 mm and 28 mm are 2 mm, 3 mm, 4 mm, 6 mm, 8 mm, 9 mm and 10 mm respectively.

The efficiencies are shown for each Lc where the highest efficiency is 1. However, the range of efficiencies simulated ranges from 0.06 to 0.71 or 6% to 71% depending on the coupling length. From Fig. 13, the longer the coupling length, the higher the coupling efficiency.

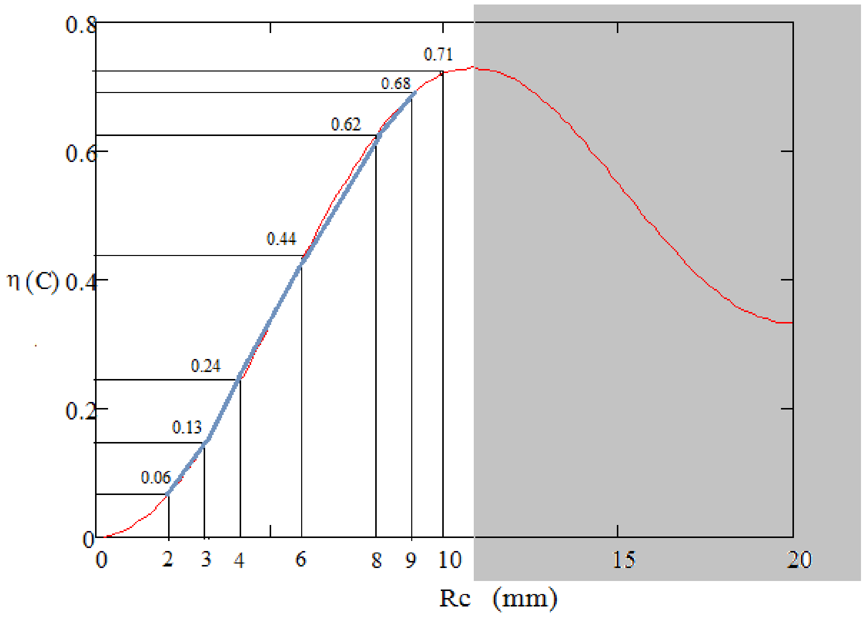

Fig. 13. Coupling Efficiency Obtained by MathCAD Simulation Using CMT and Hertz's Law Integrated Equation.

Figure 14 shows the plotted values of efficiency between the simulated efficiency of CMT and Hertz's Law and experimental splitter efficiency having different bending radii and coupling length. From the graph, the pattern of both graphs are similar although the different values of efficiencies between the simulated and experimental values show losses that are due to insertion losses of the fibers, imperfect alignment between the fibers and the meters and long tapered length of the cores where bending results in stimulating the rays to radiate out of the fibers. However, due to small bending radius of 10 mm, 13 mm and 16 mm, the values of the efficiencies are higher that simulated values since the analytical formulae does not account bending parameter.

Smaller bending radius of the splitter stimulates the rays to radiated and transfer from the first fiber to the second fiber extensively. However, as the bending radius gets larger, bigger bending angle is observed, thus, bending hardly affect the coupling and splitting of the splitter, rather, the longer coupling length between the lapping cores helps the coupling between the fibers. The larger bending slows the radiation rate of the rays to the second fiber. In addition to the experimental condition of the fibers, i.e., insertion losses and long tapered length, therefore, the efficiencies of the splitter in experiment are lower than the simulated values at larger bending radius and longer coupling length.

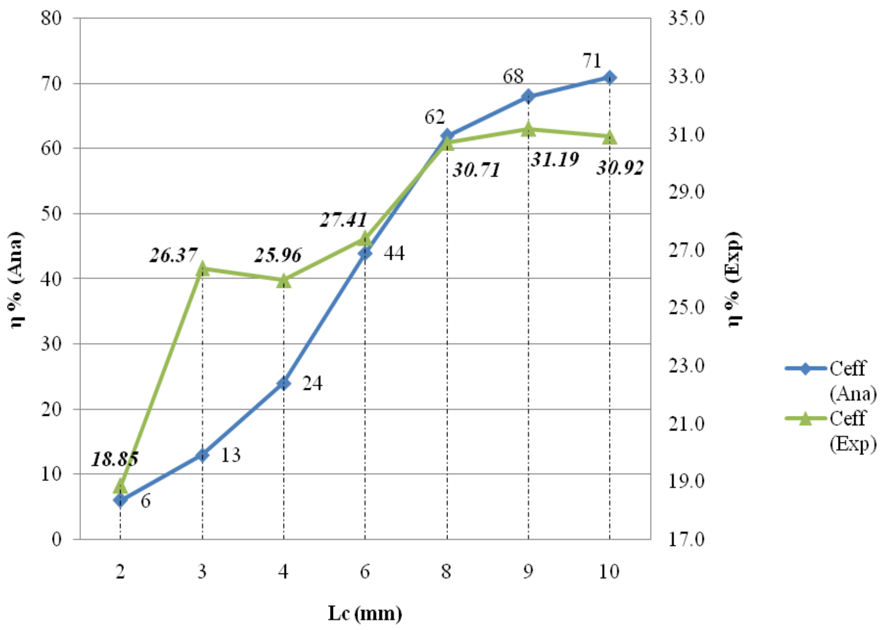

Fig. 14. Comparison between Coupling Efficiency by Simulation and Efficiency by Experimental.

5. Conclusions

Characterizations and analysis done show which bending radius is optimum for the prepared splitter. For the particular splitter, for normal force imposed, the bending radius that gives the highest splitting ratio is 10 mm, 22 mm and 13 mm. However, for the smallest excess loss, the bending radius that gives the minimum loss is 19 mm, 16 mm and 13 mm. Thus, the optimum bending radius with highest splitting ratio and lowest excess loss is 13 mm for splitter of core diameter between 0.75 mm -0.85 mm, etching length of 25 mm with force of 0.3 lbF which is normal force. For given force exertion, 3.0 lbF, the bending radius that gives optimum splitting ratio is 19 mm, 22 mm and 13 mm.

For lowest excess loss, the bending radius that gives minimum loss is 19 mm, 16 mm and 25 mm. Thus for this particular splitter with given force, the best bending radius that gives optimum splitting ratio and low excess loss is 19 mm bending radius. Therefore knowing the compatible bending radius for the prepared splitter of core diameter, Dc of 0.75 mm-0.85 mm, etching length of 25 mm for both normal force and given force, we can develop an efficient splitter that can give the highest splitting ratio with minimum losses based on the study done for multimode step-index fiber.

This study also analyses the efficiency of the splitter having different bending radius and coupling length. The pattern of efficiency is quite similar, however, due to insertion losses of the lapping fibers and long tapered length of the cores lead to low efficiency observed for experimental values.

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