The optimum conditions for arc fusion to splice photonic crystal fiber and single mode optical fiber

Dr Mohammed S. Mehde
Email:Mosame_11@yahoo.com
Laser and Optoelectronics Engineering Dep,University of Technology/Baghdad.
Dr. Salah Aldeen Adnan Taha
Email:salahadnan9999@yahoo.com
Laser and Optoelectronics Engineering Dep,University of Technology/Baghdad.
Ammar Anwer Ahmed
Laser and Optoelectronics Engineering Dep,University of Technology/Baghdad.
Email:amar.scopesky@gmail.com

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ABSTRACT

This search deals with the empirically obtained conditions for the fusion splicing with photonic crystal fibers (ESM-12) and (SMF-28) by controlling the arc-power and the arc-time of conventional electric-arc fusion splicer (FSM-60S). The development of microstructure fiber has been limited by the fact that these fibers are generally difficult, and in some cases even impossible, to fusion splice using conventional technologies. For this reason, fusion splicing microstructure fiber is an important area of research that is likely to impact the future direction of optical fiber technology . there are many kinds of fusion splicing techniques, enabling connection between two optical fibers, such as an electric arc and a CO_2 laser .It is likely that electric arc fusion splicing technique has been widely applied and even better established than the others, especially on the standard single mode fibers (SMFs).

الظروف المثالية للحام القوس لربط ليف ضوئي كرستالي مع ليف بصري احادي النمط

الخلاصة

البحث يتعامل مع الشروط العملية للحام بين ليف ضوئي بلوري نوع (ESM12) مع ليف احادي النمط (SMF28) بواسطة السيطرة على القدرة وزمن الانصهار لجهاز اللحام نوع (FSM-60s). تطور الالياف البلورية مقيد بسبب تركيبه المعقد ومن الصعوبة لحامه لهذا السبب يعتبر لحام الليف البلوري من البحوث المهمة . هناك عدة طرق للحام , تعمل على ربط الالياف الضوئية , احدى هذه الطرق هي تقنية اللحام باستخدام لحام القوس الكهربائي او باستخدام تقنية CO_2 laser. وتعتبر طريقة اللحام الكهربائي هي اكثر الطرق استعمالا وأفضل من الطرق الاخرى , وخاصة للحام الالياف احادية النمط.

Keywords : Fusion time, fusion Power, Arc fusion splicer, photonic crystal fiber , Optical fiber, splice loss .

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

INTRODUCTION

One of the attractive properties of the photonic crystal fiber (PCF) is their possibility to be single- moded over a wide wavelength range, surpassing the ordinary single- mode fibers which become multi mode for wavelength below their single-mode cut-off wavelength . PCF which are specially designed with this property are called the endlessly single mode fiber (ESM) PCF [1] . The majority of fiber devices, such as optical sources, detectors, switches, interrogation units etc., use standardized telecom fiber connectors. Therefore, most of the practical applications of specialty, including photonic crystal, side-hole, air-clad etc., fibers require a reliable and repeatable low-loss splicing with a standard single mode fiber (SMF) [2]. Although strongly demanded, such splices are still one of the fundamental issues for realistic PCF applications due to the completely different inner structure of SMFs and PCFs, additionally lately there has been an extensive attention paid to the use of small core and/or large air filling factor PCFs for different applications, such as gas and liquid spectroscopy [3, 4], surface-plasmonresonance sensors [5,6], mechanical sensors [7], nonlinear exploitation [8,9] and others. The possibility of splicing PCFs to conventional fibers or alternatively to another PCF is essential for transmission or signal processing applications. PCFs can be spliced to other fibers using splicers used for conventional fiber technology. Optimizing the heat temperature and the heating time in order to avoid the collapse of the cladding holes, There are several basic ways to connect PCFs and SMFs (a number of methods for connecting PCFs and SMFs) Simple, effective and low-cost way to splice different PCFs with conventional SMFs is fusion splicing technique, since fusion splicing is the most mature technology in splicing fibers and commercial fusion splicers are widely used [10]. The goal of this work is to get the minimum value of splice loss between photonic crystal fiber type (ESM-12) and single mode fiber using fusion splicing by trial and error method.

Arc fusion splicing:

Fusion splicing is act of joining two optical fibers end-to-end using heat. The goal is to fuse the two fibers together in such a way that light passing through the fibers is not scattered or reflected back by the splice, and so that the splice and the region surrounding it are almost as strong as the virgin fiber itself. However, low loss connection between PCFs and single mode fibers (SMFs) using a fusion splicer is still a challenge due to two main reasons: one is that the mode mismatch between a SMF and a PCF causes the coupling loss; the other is that the air holes of PCFs in the joint part is easy to collapse completely in practical operations, which increases the fiber loss due to destroying the light guiding structure in the joint part [11]. By changing the parameters of the splicer, low-loss splicing will do, depending on the characteristics of PCFs used and the splicer, during fusion process, the fiber tips are heated to soft point in the area of arc splicer and are then pressed to form a joint. In softening point, the surface tension will overcome the viscosity and cause the PCF’s cylindrical air holes to collapse, Viscosity inhibits fiber deformation since deformation requires relative motion and shear [12], the softening points of PCFs and SMFs are different, and also diameter. The rate of collapsing in PCFs during fusion can be calculated by using below equation [13]:

$$V_{collapse} = \frac{y}{2\eta} \quad \dots (1)$$

Where
y, η are surface tension and viscosity, respectively.

The viscosity of fused silica (PCF) sharply decreases with increasing temperature. Fused silica is a glassy form of silicon dioxide (SiO_2). In comparison to most multi-component glasses, fused silica exhibits relatively slow decrease of viscosity with temperature figure (1). For fusion splicing, this property is desirable, as larger variations in temperature can be tolerated [14].

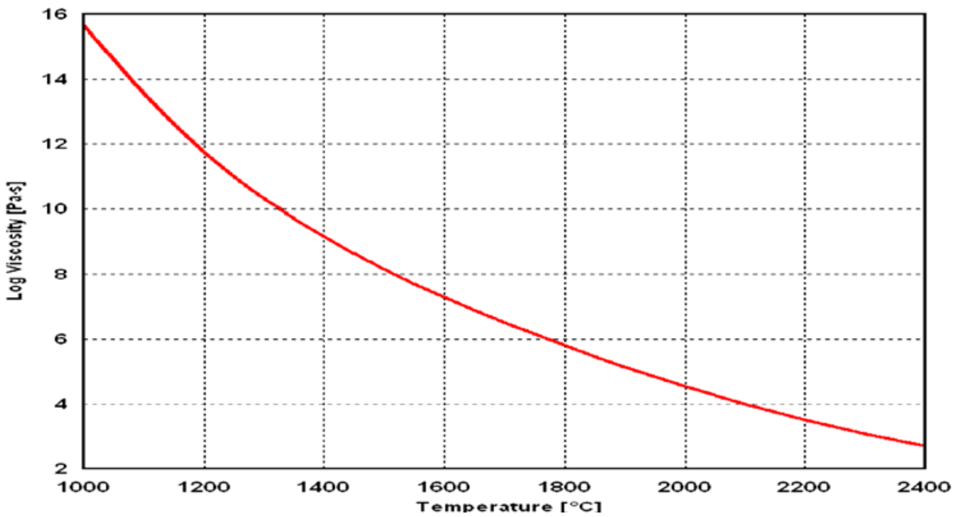
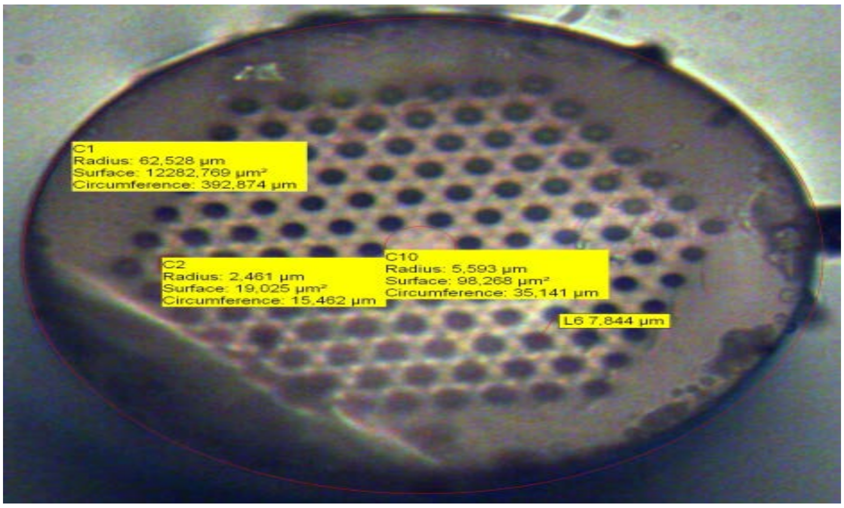


Figure (1): Viscosity of pure fused silica as function of temperature

In order to form a fusion splice, the fiber must be softened, meaning that its viscosity must be reduced to a certain value (typically about 10^5 Poise where 1 poise = 1g/cm .s=10kg/m.s) by heating it above 2000^o C [14].

The Experimental Procedure

In our experiment, SMF-28 was used , which is considered the standard optical fiber for telephony,cable television, cladding diameter($125\pm1.0\mu m$) and core diameter ($9\pm0.5\mu m$) [15,16], The type of the photonic crystal fiber used in the research is (ESM -12)as shown in figure (2), this single mode photonic crystal fiber is optimized to low loss across 700 nm to above 1700 nm while keeping an almost constant mode field diameter , the fiber is endlessly single-mode with no higher order mode cut-off and delivers excellent mode quality at all wavelengths . the fiber has a standard 125 μm outer diameter core diameter 12 ± 0.5 μm and is compatible with all common fiber tools . The experimental set-up used is shown in figure (3) it consists of short length of PCF (ESM-12) with length of 3 cm spliced in both sides with SMF-28 using fusion splicer **(FSM-60S)** with light source and power meter .



Figure(2) Cross section area of photonic crystal fiber (ESM-12) under microscope

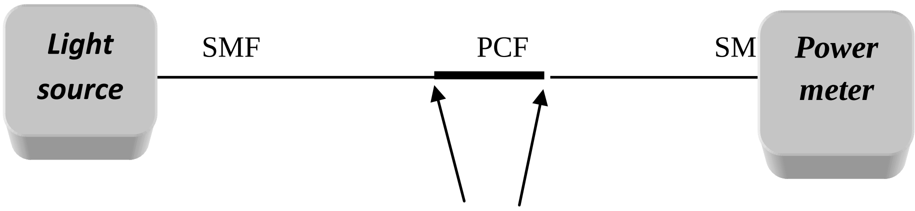


Figure (3): schematic of splicing (SMF-28/ESM-12/SMF-28)

Optimum parameters of the fusion splicing have been selected to splice ESM-12 (PCF) to SMF-28 to accurately measure the splice loses the experiment was setting as follows: first, the transmission power in SMF-28 was measured by power meter and light source with wavelength of 1550nm and recorded as a reference measurement, secondly, the SMF-28 was cleaved at the middle part. Thirdly, the two sides of the optical fiber were stripped by (JIC – 375 Tri – Hole) stripper and the protective polymer coating around optical fiber was removed.

Fourthly, the optical fiber was cleaved perpendicular to the longitudinal axis of the fiber. In our experiments Fiber Optic Cleaver (CT-30) was used. Step five was done by cleaning the conventional single mode fiber (SMF-28) by Alcohol and tissue. Step six was done by stripped ESM-12 with_(JIC – 375 Tri – Hole) stripper and the protective coating around optical fiber was removed. Finally Photonic crystal fiber (ESM-12) was cleaved perpendicular to the longitudinal axis of the fiber by Fiber Optic Cleaver (CT-30) and cleaned by tissue only. The experiment has been working in two ways, one splice losses as a function of the fusion time when the fusion power is fixed, And other splice losses as a function of the fusion power when the fusion time is fixed. The arc fusion splicer type (FSM-60S) was setup at typical parameters, these typical parameters were gap (15µm), and overlap (10µm).

The two cleaved ends of SMF-28 and PCF (ESM-12) were placed in the splicer type (FSM-60S) the first step spliced by select different fusion time with constant value fusion power then in the next step we are select different fusion power with constant value fusion time. The other side of PCF (ESM-12) and SMF-28 were placed in the splicer type (FSM-60S) the first step spliced by select different fusion time with constant value fusion power then in the next step we are select different fusion power with constant value fusion time. The transmission power losses in (SMF-PCF-SMF) were measured by using 1550nm wavelength, the loss of splice points were calculated by using the equation (2).

$$\alpha\ [dB/m] = -\frac{10}{L}\log\left(\frac{p_t}{p_o}\right) \qquad \text{.... (2)}$$

Where

($\propto$) the fusion splice loss in (dB/m) of one point, (P_t) is output power after fusion splice, (P_0 500µW) is power source (Reference measurement) before fusion splicing.

Results and Discussion :

The experimental works were used trial and error method as shown below :

1. Splice losses of (SMF / PCF / SMF) as a function of the fusion arc time at fixed arc power:

The transmission power in (SMF-PCF-SMF) were measured by using light source of 1550nm wavelength, The input power in (SMF -PCF-SMF) from light source was 500 µw and the losses were calculated by using the equation (2), the transmission power and Splice losses of optical fiber (SMF-28/PCF (ESM-12)/SMF-28) were given in tables[(1) and (2)] at fixed power STD-10 (bit) and STD+10 (bit) respectively **.**

Table (1) when the arc power is fixed at STD-10 bit

Arc Time (ms)	Arc power (bit)	Output powerfor two points(µw)	Tota (α) Splice loss for two points(dB)/m	Coupling efficiency
1000	STD-10	390	0.21	78%
1500	STD-10	370	0.26	74%
2000	STD-10	395	0.204	79 %
2500	STD-10	450	0.09	90 %
3000	STD-10	457	0.07	91.4%
3500	STD-10	369	0.28	72%
4000	STD-10	350	0.3	70%

Table (2) when the arc power is fixed at STD+10 bit

Arc Time (ms)	**Arc power (bit)**	**Output powerfor two points(μw)**	**Total(α) Splice loss for two points(dB)/m**	**Coupling efficiency**
1000	STD+10	320	0.387	64%
1500	STD+10	330	0.360	66%
2000	STD+10	400	0.193	80 %
2500	STD+10	410	0.172	82 %
3000	STD+10	413	0.166	82.6%
3500	STD+10	370	0.26	74%
4000	STD+10	301	0.440	60.2%

The relationships between splice loss and fusion arc time for constant fusion arc power were taken from table (1) and table (2) and illustrated in figures (4) and figure (5) respectively as follows:

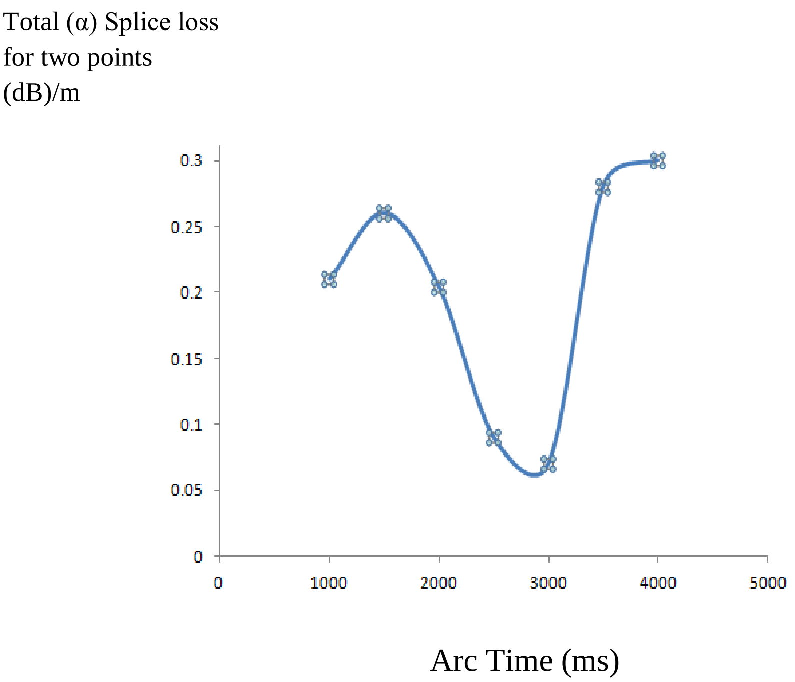


Figure (4) Splice losses of SMF-PCF as a function of the arc time at the arc power STD - 10(bit).

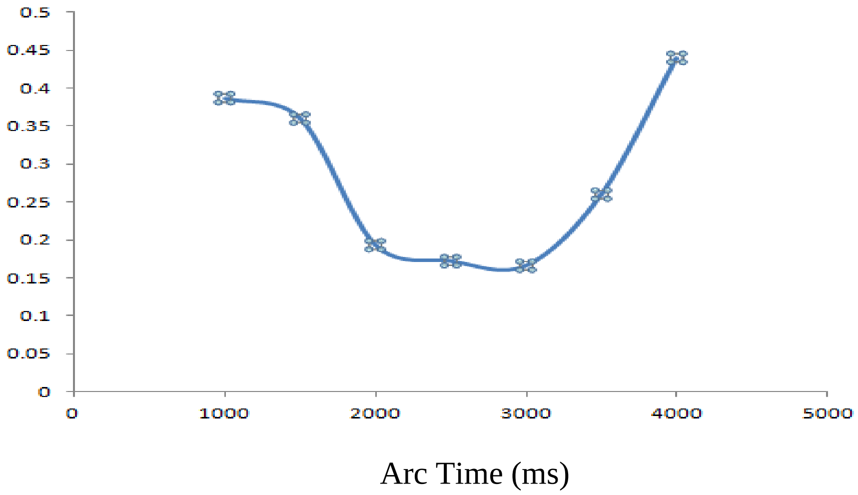


Figure (5) Splice losses of SMF-PCF as a function of the arc time at the arc power STD + 10(bit).

MFDs in SMF-28 and ESM-12 in PCF are equal, the overlap is (10 µw) , and Gap(15 µw) . From fig.(4) and (5) the fusion power was fixed at STD - 10(bit) and STD + 10(bit) respectively and varied the fusion time from (1000 to 4000) ms with a step of 500 ms .

From table (1) and figure (4) the fusion power was fixed at STD - 10(bit) and varied the fusion time from (1000 to 4000) ms with a step of 500 ms, we denoted that the smallest value of lose (0.07dB/m) (0.09dB/m) were achieved when the Arc time was 3000 ms and 2500ms respectively due to increase temperature and decrease viscosity of SMF-PCF joint which will cause air- holes collapse of the PCF to degree that does not alter the mode field in PCF and mode field kept equal between two fibers, therefore we get a suitable Arc power and Arc time to soften the tips of the PCF and the SMF to achieve a good mechanical strength of the joint ,minimize the collapse of air holes, so there is a tradeoff between splice loss and mechanical strength , and achieved coupling efficiency of 91.4% when lose(0.07dB/m) and 90 % for (0.09dB/m) lose. When the fusion time less than (3000,2500 ms) the splicing losses maximize due to low temperature and very short air- holes collapse of the PCF which will cause weak splice joint which will easily break and bad mechanical strength between two fibers, when the fusion time more than (3000 ms) the splicing losses maximize due to high temperature and long air- holes collapse of the PCF which will cause mode field mismatching between two fibers.

From table (2) and figure (5) the fusion power was fixed at STD + 10(bit) and varied the fusion time from (1000 to 4000) ms with a step of 500 ms. The smallest splice loss (0.166dB/m) was achieved when the arc time was 3000ms due to increase temperature and decrease viscosity of SMF-PCF joint which will cause air- holes collapse of the PCF to degree that does not alter the mode field in PCF and mode field kept equal between two fibers, and get coupling efficiency of 82.6% at this point. When the fusion time less than (3000 ms) the splicing losses maximize due to low temperature and short air- holes collapse of the PCF which will cause weak splice joint which will easily break and bad mechanical strength between two fibers , when the fusion time more than (3000 ms) the splicing losses maximize due to high temperature and long air- holes collapse of the PCF which will cause mode field mismatching between two fibers.

From figure (4) the corresponding smallest loss (0.07 dB/m) when the fixed arc power is STD - 10(bit) at arc time (3000) ms is shown in figure (6), because of increase the Arc time to (3000) ms the holes of the PCF collapse was increased to a certain degree that does not alter the mode field in PCF and mode field kept equal between two fibers and hence minimizes the splicing loss to (0.07dB/m).

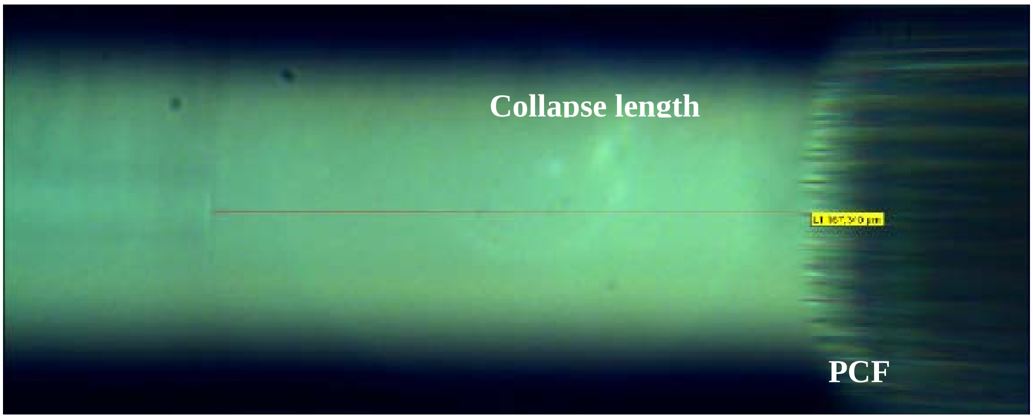


Figure (6): Microscope image of the splice zone between PCF (ESM-12) on the right, and the SMF-28 on the left. The collapsed length is ~147.340µm at STD - 10(bit) and Arc time (3000) ms.

From figure (5) the corresponding max. splice loss for (0.387 dB/m) at fixed Arc power STD + 10(bit) and Arc time (1000) ms is shown in figure (7),the air- holes collapse of the PCF is minimal and the splice loss is large (0.387 dB/m) due to low temperature, high viscosity, the fiber tips dose not reach to softening point and poor mechanical strength .

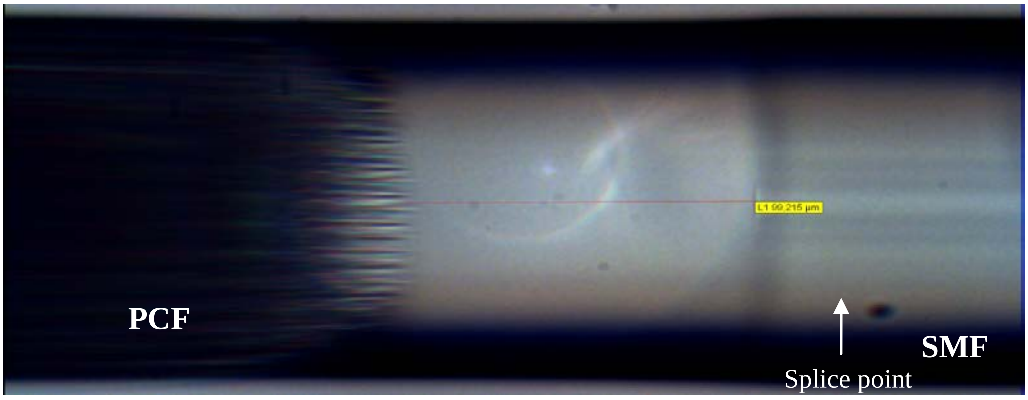


Figure (7): Microscope image of the splice zone between PCF (ESM-12) on the left, and the SMF-28 on the right. The collapsed length is ~99.215µm when the Arc power is STD + 10(bit) and Arc time (1000) ms.

From figure (5) the corresponding smallest loss (0.166 dB/m) when the fixed arc power is STD + 10(bit) at arc time (3000) ms is shown in figure (8),because of increase the Arc time to (3000) ms the holes of the PCF collapse was increased to a certain degree that does not alter the mode field in PCF and mode field kept equal between two fibers and hence minimizes the splicing loss to (0.166dB/m).

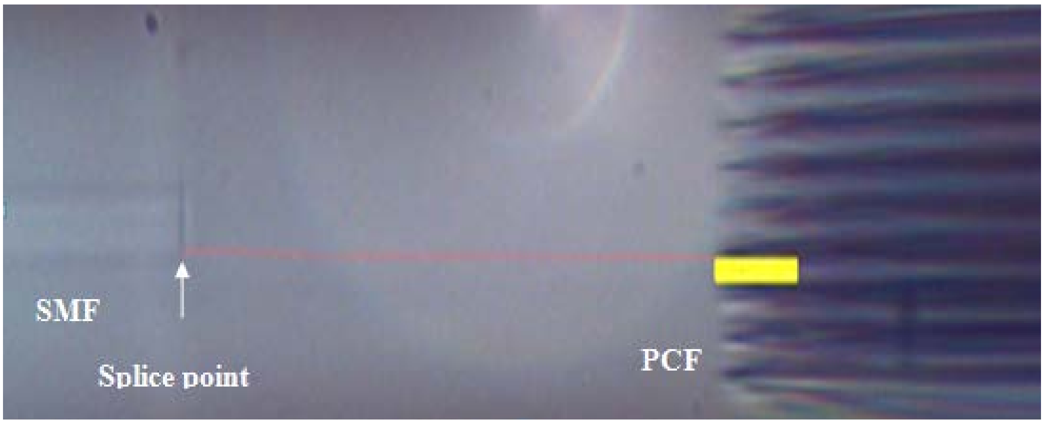


Figure (8): Microscope image of the splice zone between PCF (ESM-12) on the right, and the SMF-28 on the left. The collapsed length is ~185.340µm at STD + 10(bit) and Arc time (3000) ms.

2. Splice losses of (SMF / PCF / SMF) as a function of the fusion arc power at fixed arc time:

The transmission power in (SMF-PCF-SMF) were measured by using 1550nm wavelength and the losses were calculated by using the equation (2), the transmission power and splice losses of optical fiber (SMF-28/PCF (ESM-12)/SMF-28)were given in table (3) at fixed arc time 1000 ms.

Table (3) when the arc time is fixed at 1000 ms

Arc power (bit)	**Arc Time (ms)**	**Output power for two points (µw)**	**Total (α) Splice loss for two points (dB)/m**	**Coupling efficiency**
STD-40	1000	398.5	0.197	79.6 %
STD-30	1000	320.8	0.385	64.16 %
STD-20	1000	367.5	0.267	73.5 %
STD-10	1000	391.5	0.212	78.3 %

The relationships between splice loss and fusion arc power for constant fusion arc time were taken from table (3) and illustrated in figure (9) as follow:

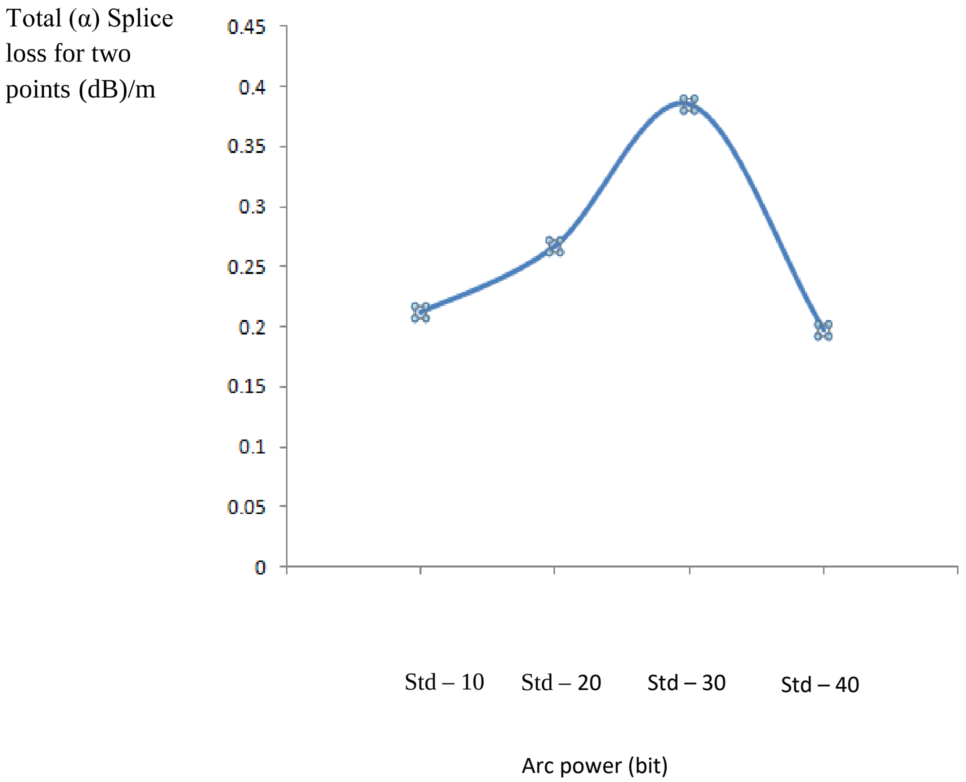


Figure (9) Splice losses of SMF-PCF as a function of the fusion power when the fusion time is fixed at(1000 ms.)

MFDs in SMF-28 and ESM-12 in PCF are equal. the overlap is (10 µw) , and Gap(15 µw) . In figure(9) the fusion time was fixed at 1000 ms and varied the fusion power. The smallest loss (0.197 dB/m) was achieved when the fixed arc time was 1000 ms at arc power STD - 40(bit) due to minimum temperature and viscosity of SMF-PCF joint which will cause minimum air- holes collapse of the PCF and does not alter largely the mode field diameter of PCF and kept equal with mode field diameter of SMF but we are get a weak splice joint which will easily break and bad mechanical strength between two fibers, and therefore we are get coupling efficiency of 79.6 % is not the optimum value .

When the Arc power are (STD-10 , STD-20 and STD-30)bits the value of splice lose was not optimum due to minimum temperature , viscosity of SMF-PCF joint and low arc power that lead to weak splice joint which will easily break and bad mechanical strength between two fibers .

From figure (9) the corresponding splice loss for (0.116 dB/m) at fixed arc time 1000 ms and arc power STD-40(bit) is shown in figure(10).

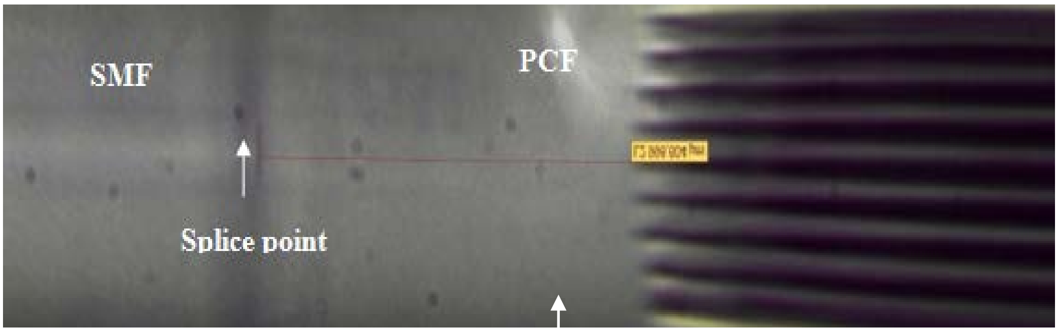


Figure (10): Microscope image of the splice zone between PCF (ESM-12) on the right, and the SMF-28 on the left. The collapsed length is ~90.604 at STD - 40 (bit) and Arc time 1000 ms

From figure (9) the corresponding splice loss for (0.385 dB/m) at fixed arc time 1000 ms and arc power STD-30(bit) is shown in figure (11).

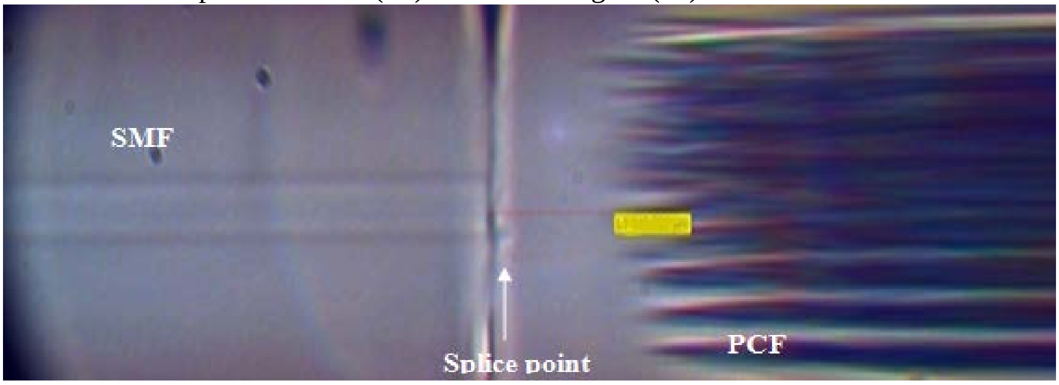


Figure (11): Microscope image of the splice zone between PCF (ESM-12) on the right, and the SMF-28 on the left. The collapsed length is ~92.726µm at STD - 30 (bit) and Arc time 1000 ms

CONCLUSION

The research regard to coupling efficiency between single mode fiber with core diameter 9 µm and mode field diameter 10.4 µm at 1550 nm with solid core photonic crystal fiber type (ESM 12) of core diameter approximately 12 µm and mode field diameter 10.5 µm at 1550 nm , using fusion splicing type fujikora FSM (60 S) , depending on the two parameters of the devise the first one fusion time the others fusion power , We have adopted the method of trial and error to get minimum splice loss between them , by fixed the fusion power and varied the fusion time and vice versa . The smallest loss (0.07dB/m) was achieved when the Arc time was 3000 at fixed Arc power(STD - 10(bit)) due to increase temperature and decrease viscosity of SMF-PCF joint which will cause air- holes collapse of the PCF to degree that does not alter the mode field in PCF and mode field kept equal between two fibers, therefore we get a suitable Arc power and Arc time to soften the tips of the PCF and the SMF to achieve a good mechanical strength of the joint ,minimize the collapse of air holes . so there is a tradeoff between splice loss and mechanical strength, and get the optimum coupling efficiency at this point was 91.4% .

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