

doi:10.15199/48.2022.05.06

Thermal removing the primary coating layer from the fiber optic surface

Abstract: The article describes a new technology of thermal removal of the acrylic coating layer from optical fibers. Based on the analysis of the results of thermo-gravimetric tests, the decomposition temperature of the acrylic layer was determined, and then, knowing the optical and geometric parameters of optical fibers, a prototype of a device for the automatic removal of the protective layer from the terminal of optical fibers was built. The designed control system and the prototype of the device, which consists of a 6-axis robot, vision system and regulators, were presented. The efficiency of the proposed method and the device made was compared with the existing systems. It has been shown that it will be possible to remove acrylic layers much faster than before, while maintaining very good quality of optical fibers. Due to these advantages, the presented technology can be successfully used in industrial lines intended in the fiber optic connectorization process.

Streszczenie: W artykule opisano nową technologię termicznego usuwania warstwy pokrycia akrylowego z włókien światłowodowych. Na podstawie analizy wyników badań termo-grawimetrycznych wyznaczono temperaturę rozpadu warstwy akrylowej, a następnie znając parametry optyczne oraz geometryczne światłowodów zbudowano prototyp urządzenia do automatycznego usuwania warstwy ochronnej z ich końcówek. Przedstawiono zaprojektowane układy sterownia oraz urządzenia wykonawcze, których najważniejszymi elementami są: robot sześcioośowy, układ wizyjny oraz system regulatorów. Wydajność zaproponowanej metody oraz wykonanego prototypu została porównana z innymi urządzeniami wykorzystywanymi w praktyce. systemami. Pokazano, że można będzie znacznie szybciej niż dotychczas usuwać warstwy akrylowe przy zachowaniu bardzo dobrej jakości powierzchni włókien szklanych. Dzięki tym zaletom przedstawiona technologia może być z powodzeniem zastosowana w przemysłowych liniach przeznaczonych do łączenia włókien światłowodowych. (Termiczne usuwanie warstwy pokrycia akrylowego z włókien światłowodowych)

Keywords: primary coating, fiber optic, fiber optic connectorization, industrial automation.

Słowa kluczowe: powłoka akrylowa, włókna optyczne, łączenie włókien światłowodowych, automatyka przemysłowa.

Introduction

The fiber optic industry is developing year over year due to civilization progress demand. Which means fiber optic solutions have to be delivered faster and cheaper while maintaining a high level of the fibers quality. Optical fibers are applied in many different applications in various environmental conditions, especially in communication and measurement systems, where the quality and speed of the transmitted signal are of paramount importance. The most common applications are: data centers, central offices, rail and highway infrastructure, building connections, submarine information infrastructure and industrial automation. Fiber optic cables are used in communication over long distances (hundreds of kilometers), ensuring high signal quality. Optical fibers are effectively protected in order to take advantage of their excellent transmission properties in a given environment for the required service time. Furthermore, the optical fibers are protected against external and internal mechanical forces arising during assembly and operating conditions. [1]

Typically, the fiber optic (Figure 1) consists of: a core, cladding and primary coating. The core is a physical medium that transmits optical information signals from an appended light source to the accepting receiver. There are three most commonly used multimode sizes: 50 μm , 62.5 μm and 100 μm and single-mode cores, which are usually less than 10 μm . The cladding (125 μm diameter) is made of an optical material – pure silica that surrounds the core. Its main functionality is a protection the core and reflect light back into the core. The primary coating is made of an acrylic, which completely surrounds the cladding. The main function is a protection glass surface against the influence of the external environment, humidity, oxygen and other weathering. This layer is coated at the last step in fiber optic manufacturing and thickness of the coated fibers are from 250 μm to 300 μm . [1][2]

Construction of primary coating surface consists of internal and external acrylic layers. Young's module of the inner primary coating, must be sufficiently low to cushion

and protect the fiber against stress on the fiber surface. The cushioning effect has to be ensured throughout fibers lifetime. The outer primary coating protects fiber against external forces and environment. Glass transition temperature has to be lower than predicted the lowest expose temperature. Both inner and outer primary coating is manufactured in the photopolymerization process and is cured using UV lamps. The inner primary coating contains a (meth)acrylate, while the outer primary coating contains an urethane acrylate. [3][4][5][6][7].

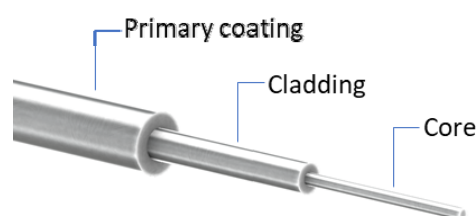


Fig. 1. Construction of a fiber optic.

Connectors include fiber count from one to even more than 24 fibers. Basically, a multifiber connectorization process covers operations such as: hardware components installation, primary coating removing, fibers installation, polishing, measurement operations and packaging. Each step of the connectorization process is very essential, however, fibers stripping process is responsible for fibers alignment in the ferrule (that has impact on an insertion loss and return loss) and mechanical strength of the connection. Incompatibilities occurring in the stripping process can be found in the measurement station. Nevertheless, some connector issues can be found only in the customer application, what may has consequences of expensive customer complaints. [1][8][9]

Overview of technologies applied to remove primary coating layer

Current technologies applied in the stripping process rely mainly on mechanical tools and they are accessible on the market shelf. However, they are not sufficient and does not obtain high quality requirements and in consequence it is necessary to execute additional process steps. Thus, there is a strong demand to develop new technology in the fiber optic industry. Most techniques allow the primary coating to be removed from one fiber at a time, which is incomparably easier than removing from multiple fibers. From processing point of view, it is possible to strip each fiber from the ribbon separately, however, it is time-consuming and also creates many issues with a bare fiber management. Depends on a medium employed in stripping process, the following methods could be distinguished: mechanical, chemical reaction, laser radiation, thermal interaction.

Mechanical methods remain many impurities on the fiber surface in the stripping process. Thus, it is required to introduce additional process steps in order to clean fibers. These techniques are fully operator dependent that impacts on a reliability and generate many issues in the process. It is possible to highlight two major types of the mechanical tools: micro-stripper and ribbon fiber stripper. Micro-stripper is a hand tool that represents the simplest and the cheapest technology. The tool is dedicated to strip one fiber. Operation is based on opposite aligned blades which are around the fiber. A measuring stick that is implemented on the tool allows to strip fiber in the exact length.

A ribbon fiber stripper is designated to remove primary coating layer from the high fiber count ribbons. Fibers have to be inserted into temporary holder, which is inserted into the device. The fibers are heated up to 100°C within 30 seconds and then using built in blades the primary coating layer is removed by the operator. The probability of the fiber damage is very high due to moving blades that causes a fiber scratching and breaks.

From chemical point of view exists many opportunities to remove acrylic layer using solvents applied in specific conditions. The information about a chemical composition of the primary coating layer is restricted and is not fully known. However, there are still exist some methods dedicated for acrylic coated fiber optic glass, which have been verified in terms of effectiveness and fibers damages. [10]

One of the chemical substances that is applied to remove acrylic layer is propylene glycol in high temperature. The method is utilized in coatings made of EVA (ethylene-vinyl acetate), UV-cured epoxy acrylate and UV-cured polyester thiol. The process based on dipping the coated fiber into a tank with propylene glycol at 160°C within approximately 30 seconds. Then, the coating is mechanically removed by clamps which hold the coating during fibers withdrawal from the tank. The method is based on reducing interaction between silica and coating layer and subsequently mechanical removal of acrylic. [10]

The alternative method is utilizing a methylene chloride (*MeCl*). The coated fiber is dipping in a solvent at an ambient temperature for a few seconds and then the coating is removing using a hand stripper or manual pulling. The acrylic coating softens and swells due to the penetration of solvent molecules between the polymer chains, reducing the strength of the interactions, thus destabilizing the fiber-coating connection. The method is less chemically aggressive, however the mechanical stripping could affect fiber damages. [11]

Another method is usage a sulfuric acid in high temperature. At the beginning, the coated fibers are immersed in sulfuric acid at temperature approximately 180-

200°C for 20 seconds. In the second step the fibers are rinsed off by acetone and water in order to remove any acid remains. Lack of an additional mechanical components to strip fibers is a significant advantage of this method. Thus, the probability of the fiber damage is significantly low. The Atomic Force Microscope (AFM) analysis shows that this method does not generate any fiber structure damages. The method removes not only the acrylic layer, but also thin layer of hydrated silica what AFM profiles confirms. Research shows that utilizing hot acid does not affect the fibers strength during its future lifetime. Furthermore, the strength does not depend on the immersion time and aggressive chemical conditions do not affect degradation of the fibers. [11][12]

Chemical coating removing may be carried out by usage of two solvents as well. The temperature of the process is between 20-80°C while immersing time is in range of 30-90 minutes. One of the first compound may be as follows: trichloromethane, methylene dichloride, ethylene dichloride, 1,3-propylene dichloride, 1,4-dichlorobutane or chloroform. While the second solvent may be: acetone, butanone, pentanone, hexanone or octanone. Both solvents are mixed according to the mol ratio from 1:10 to 1:1. Subsequently, the coated fibers is soaked by the prepared mixture. Afterwards, the fibers are inserted into a sonic oscillation groove with an alcohol in order to remove acrylic remains. Finally, drying with pure nitrogen is applied in order to achieve pure silica surface. During immersion of the fibers the interaction between silica and coating layer is decreasing. In a result the acrylic layer is broken away from the silica surface in the oscillator grooves. This method is high efficiency, however requires preparing mixture of solvents, oscillation of the fibers and nitrogen purification. That makes this method difficult to applied in industrial conditions. [13]

The most common laser type that is applied in fiber optic stripping is a carbon dioxide laser with pulsed output (CO_2). Wavelength of the emitted light is in the range of 9.4 μm to 10.6 μm that corresponds to infrared radiation. This laser type is classified in Class 4 due to high emitted power, which reaches many kilowatts. The laser beam is delivered to three positions around the fiber. The primary coating is removed as result of high precision rastering motion along the fiber (Figure 2). During this process fiber has to be kept by grippers in order to ensure constant alignment. The laser technology may be used in single fiber stripping only. [14]

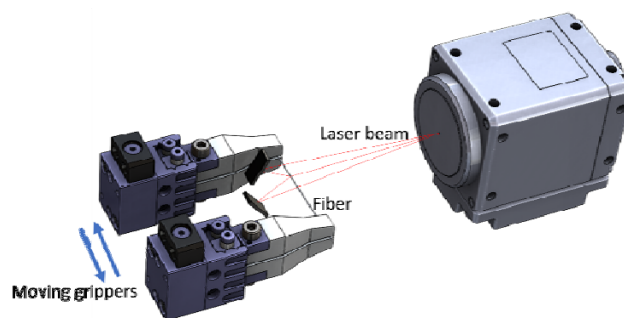


Fig. 2. View of the laser stripping process.

Thermal methods

Thermal interaction gives many opportunities in removing primary coating layer. There are some simplest methods such as: open flame, oven and electric arc, nevertheless due to cycle time, fiber quality and control possibility is highly difficult to implement them in the production environment. One of the techniques that may be applied to remove primary coating layer is hot air stripping.

The fibers are heated up over 900°C and then the coating is expelled by the gas flow. Fibers are tensioned up to 20 N by the high precision clamps. The air is applied by narrow nozzle which move along the fibers during the process. The process takes approximately 20 sec. and once it is finished the fibers are cleaned by chemical agent. This technique may be applied for one and multifiber products. However, for the ribbon fibers there still exists some process issues on the interface between bare fibers and their coating.

Stripping techniques are still being developed in order to improve fibers quality, process reliability and to reduce costs. Especially, thermal techniques allow to be easier control than other aforementioned methods and give opportunities to apply other types of gases than oxygene.

Process development

In order to develop a new technology, it is necessary to perform thermal tests of the basic coating layer of optical fibers. This gives information on the behavior of the acrylic during thermal annealing, in particular about the degradation of the acrylic layer. Detailed information on the chemical structure of acrylic used commercially for coating optical fibers is limited. However, the basic structure of acrylic can be considered on the basis of available literature reports [16]. They are a broad group of polymers containing acrylic acid, methacrylic acid and derivatives of these compounds. Primary coating contains an oxyglycidyl (meth)acrylate and urethane acrylate. The mechanism of thermal decomposition strictly depends on chemical compounds. Methacrylate polymers in the temperature higher than 500°C tend to undergo polymer chain defragmentation, moreover small amounts of another chemicals, such as CO, CO₂ and olefins connected with ester groups could also occur. If the pyrolysis is continuing at higher temperatures, the low molecular weight products could be generated, such as methane, ethane, ethylene, acetylene and alcohols. Methacrylate with a more complex structure undergo mostly ester decomposition rather than depolymerization.

Because of unknown detailed chemical structure of the acrylic coating used by the manufacturers is not possible to predict following decomposition products. However, apart from monomer, the low molecular weight products could occur. In case of more complex acrylates the main type of reactions is ester decomposition reactions and in results generate olefin corresponding to ester group and carbon dioxide. In poly(urethane)acrylates degradation of polymer runs at the beginning from urethane segments and subsequently the polyester groups undergo decomposition process. Following bond breakage could be connected with ester group decomposition, generates alcohols and olefins. Chemical bond between monomers could be broken with the increasing temperature, thus reducing the length of the polymer chains. In consequence, polymer chains become weaker and generate shorter chain fragments and finally low molecular weight chemical compounds. Detailed information about structure of the primary coating is restricted. An additional difficulty in determining the exact temperature of degradation is the coating of acrylic covers by polymer color layer that is approximately 2-3 μm. It should be noted, however, that based on the literature for typical optical fibers the temperature of decomposition process occurs in range from 500°C to 900°C [5]. This is very important because the temperature cannot be higher than 1000°C for which the glass turns into β-cristobalite polymorph and its optic properties will change. Thus, the temperature at which the acrylate of the primary coating decomposes depends on the particular type of optical fiber.

Thermogravimetric analysis (TGA) is a technique where the mass change of the material is measured as a function of temperature or time. Loss of weight informs about the volatilization temperature of individual chemical fractions and provide information about thermal stability of the material. The thermogravimetric plot made for selected samples of acrylic materials is presented in the Figure 3. It shows the temperature for which the degradation of the primary coating for three colored samples: blue, black and green take place. All data about researched samples is confidential, thus indicated temperatures cannot be published. At temperature *T1* the primary coating layer starts to undergo decomposition process. Then, significant part of low molecular weights compounds could turn into the gas state. At temperature *T2* the polymeric structure is completely break apart and only residual amounts of inorganic substances remain. The *T2* temperature is slightly different for each sample due to additional color layer. The new process assumes complete polymer degradation, thus the stripping process temperature must to obtain higher value than *T2*.

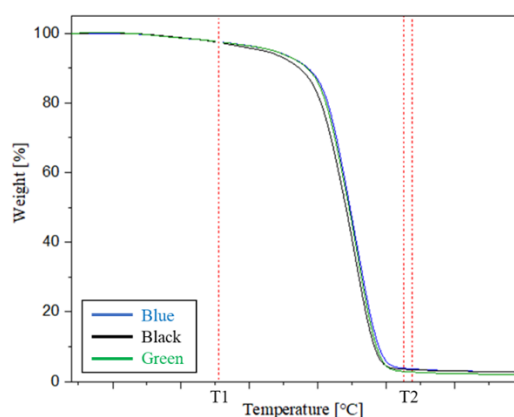


Fig. 3. Thermogravimetric analysis (TGA) of the primary coating (the exact value of temperatures *T1* and *T2* has not been provided due to the need to maintain confidential information required by the founder of this work).

It is essential that fibers and heating source have to be as close as it possible each other in the stable environmental conditions. Both, gas from the heating source and the fibers environment have to ensure the same composition of the gas mixture, in order to avoid unwanted reactions that may negative impact on the fibers. Regardless whether fibers or heating source will be moving the high precision motion has to be applied. Furthermore, fibers have to be hold by precise clamps during the process to avoid unwanted movement as result of interaction with gas flow from the heating source.

The stripping process occurs in the environment that may include variety types of inert gases such as: carbon dioxide, helium, neon, krypton, xenon and radon. However, most favorable are air, purified argon and nitrogen due to cost efficiency. The most effectiveness approach is to switch the gas between an air and another type of gas due to cost of the medium. A schematic diagram of the gas flow control system is shown in Figure 4.

In the first work cycle an electromagnetic valve *Q1* is switched off, thus an air is passing through all parts via the pneumatic valve *Q2*. In the second work cycle electromagnetic valve *Q1* is switched on and as consequence an air flow is stopped and a second gas starts to flow via pneumatic valve *Q3*. Both gases are secured against mixing and are stabilized by pressure regulator and mass flow controller.

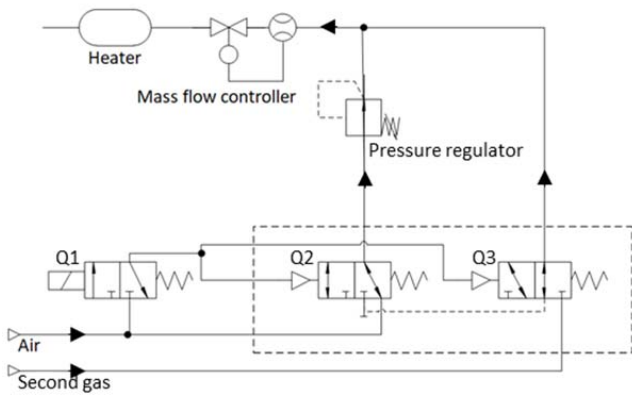


Fig. 4. Gases switching circuit. Q1 – electromagnetic valve, normally closed, Q2 – air pneumatic valve, normally open, Q3 – second gas pneumatic valve, normally closed.

During the stripping process the switching between gases significantly interrupting the stability of the temperature. Thus, it is essential to apply a high sufficiently control of the temperature profile. The temperature control circuit consists of a temperature controller and a solid-state relay (K1) (Figure 5). The temperature controller use proportional–integral–derivative control and then sets K1 which executes precise temperature adjustment and protect against exceed 1000°C.

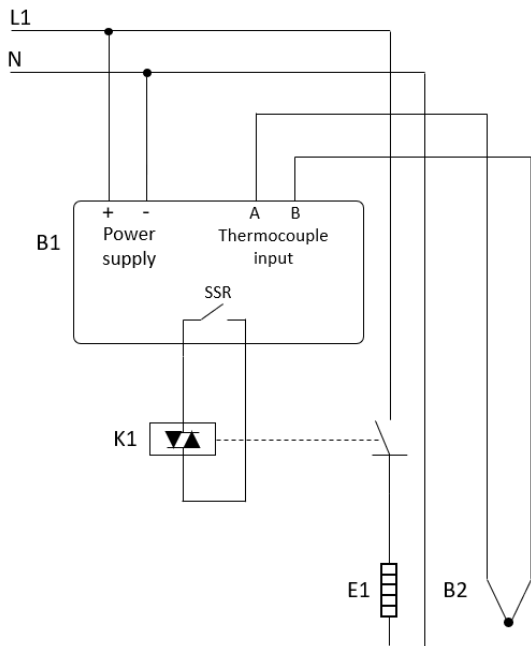


Fig. 5. Temperature controls circuit. B1 – temperature regulator, K1 – solid state relay (SSR), E1 – heating torch, B2 – thermocouple.

Dimensions of the fiber optic are very small ($\varphi = 250 \mu\text{m}$) that requires high precise motion. During the process development was applied 6-axis robot. The precision of the motion is 0,01 mm what is sufficient in this application. The process is controlled by a robot program, that includes motion and gases switching commands. The main feather of the process optimization is to apply component that allows to evaluate results. In this case camera with the light controller is applied. Figure 6 presents the effect of the control elements to the individual actuators.

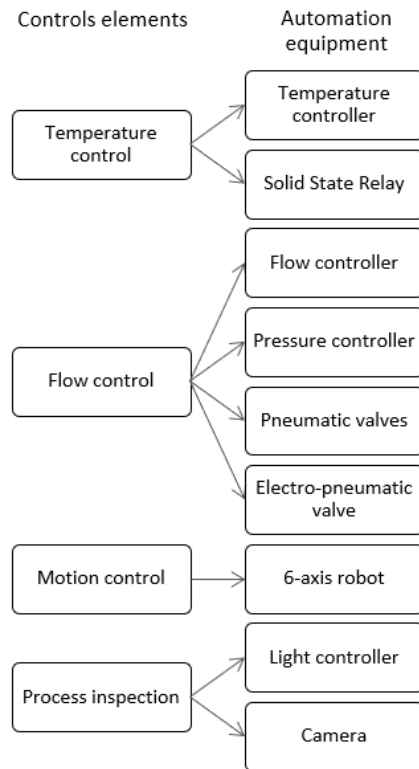


Fig. 6. Scheme of the control-actuator system.

Experimental

There are some parameters that significantly impact on the process results, such as: gas temperature, gas flow, switching time and motion speed of the fibers. The coating removing process is based on relation between these parameters and is executed in the following steps:

- fibers are held by a robot gripper,
- temperature is set to the T2 value (Figure 3),
- gas flow is switched on,
- robot starts move,
- the gas flow is perpendicular to the fibers surface (Figure 7), while the fibers are moving during the process,
- fibers are stripped,
- robot with the fibers move back from the hot gas environment.

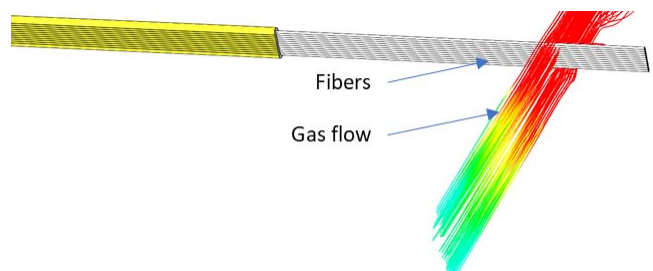


Fig. 7. Coating removing process.

The primary coating layer undergoes decomposition process due to thermal heating energy. Significant part of low molecular weights compounds turn into the gas state. Subsequently remains of the coating layer are blow out from the fibers surface. The process is very fast less than 5 sec whereas currently known similar processes take around 100 sec.

Experimental results

In order to evaluate the cleanness of the fibers they were verified under a microscope. The Figure 8 shows that fibers are free of impurities and glass damages.

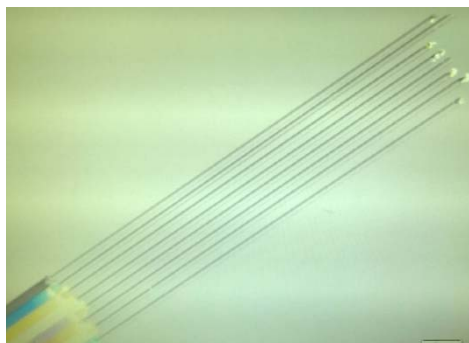


Fig. 8. Fiber optic – removed primary coating.

Based on the process requirements, fibers were installed in a connector in the connectorization line and tested in range of attenuation, geometry and visual. Finally, fibers were evaluated in the dedicated laboratory to confirm compliance with a telecommunication standard ANSI/TIA-568. Where fibers behavior in low temperature were tested, temperature life, humidity and IL (Insertion Loss) testing at ambient. All tests showed that the new technology does not have negative impact on the fibers optical parameters.

Discussion and conclusion

A new approach with hot gas could be successfully taken into account to new stripping technology for optic fibers, not only single fiber, but also twelve fibers at the same time. What is more, it should be emphasized that presented technology for twelve fibers are completely new and it has never been used and tested in manufacturing conditions. In comparison with other stripping techniques, the advantages of the hot gas stripping technology are as follows:

- the process does not involve the use of mechanical components for stripping, thus eliminating the source of mechanical damages and stresses of glass fiber,
- the innovation of the process is possibility to strip multifiber ribbons in a short time, increasing the efficiency of the stripping process,
- hot gas stripping ensures high glass fiber purity and fulfil all requirements for connectorization without any additional cleaning steps.

Described a new stripping process is designed as an automated solution, what significantly increases repeatability and quality in the connectorization process. Furthermore, this human independent stripping process

step takes less than 5 sec is incomparably faster than the currently methods used in manufactures. The quality of the fibers ensure that it is not required additional process steps. Fibers are free of impurities and damages that significantly improve connectorization process line. Taking everything into account new technology will bring significant cost benefits for the industries and end users.

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