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ORIGINAL ARTICLE

Factory site analysis of respirable fibers generated during the process of cutting and grinding of carbon fibers-reinforced plastics

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Abstract

Objectives Carbon fibers are used in a variety of industrial applications, based on their lightweight and high stiffness properties. There is little information on the characteristics and exposure levels of debris generated during the factory processing of carbon fibers or their composites. This study revisits the general assumption that carbon fibers or their debris released during composite processing are considered safe for human health.

Methods The present interventional study was conducted at a factory located in Japan, and involved on-site collection of debris generated during the industrial processing of polyacrylonitrile (PAN)-based carbon-fiber-reinforced plastic (CFRP). The debris were collected before being exhausted locally from around different factory machines and examined morphologically and quantitatively by scanning electron microscopy. The levels of exposure to respirable carbon fibers at different areas of the factory were also quantified.

Results The collected debris mainly contained the original carbon fibers broken transversely at the fiber's major axis. However, carbon fiber fragments morphologically compatible with the WHO definition of respirable fibers (length: > 5 µm, width: < 3 µm, length/width ratio: $> 3{:}1$) were also found. The concentrations of respirable fibers at the six examined factory areas under standard working conditions in the same factory were below the standard limit of 10 fibers/L, specified for asbestos dust-generating facilities under the Air Pollution Control Law in Japan.

Conclusions Our study identified potentially dangerous respirable fibers with high aspect ratio, which was generated during the processing of PAN-based CFRP. Regular risk assessment of carbon fiber debris is necessary to ensure work environment safety.

Keywords Carbon fiber · Polyacrylonitrile (PAN)-based carbon fiber · Carbon fiber reinforced plastic (CFRP) · Respirable fiber · Risk assessment

Introduction

Carbon fiber-reinforced plastic (CFRP) consists of carbon fibers and polymer resin and is an excellent functional material with better strength and lighter weight than metals. The use of CFRP has widened to include various fields, ranging from aerospace to automobiles, as well as home and hobby products, such as fishing rods and golf clubs (JCMA 2021). The composite structure of CFRP often requires machining, grinding or finishing to remove sharp edges, shaping structures to specific dimensions/finishes, and/or allowing for installation of various instrumentations. During such processes, carbon fibers and polymer resins are broken down, generating dust and fly: micro-sized filaments separated from carbon fiber (Yoder et al. 2015). Thus, during the process of cutting or grinding CFRP, debris including dust and

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fly (especially micro-particles of carbon fibers) can potentially easily distribute in the workplace.

Carbon fiber composites are classified into polyacrylonitrile (PAN)-based and pitch-based. The PAN-based carbon fibers with a fiber diameter of approximately 7 µm, produced by carbonization of PAN precursor, is the largest volume in production and use (JCMA 2021). The previous papers reported that the micro-particles generated from PAN-based CFRP contain carbon fibers of the same diameter as fibers embedded in the composite material, and concluded that the micro-particles and carbon fibers with diameters ranging from 5 to 10 µm are not respirable (Kehren et al. 2019; Wang et al. 2017). It was also reported that the debris of aerodynamic diameters of CFRP in an airplane fuselage section construction plant was always higher than 20 µm and the respirable fragments were not released (Lovreglio et al. 2020). On the other hand, another group demonstrated that some carbon fibers split along the fiber axis during the release process from composites of carbon fibers, generating smaller and respirable fibers (Schlagenhauf et al. 2015). However, so far, there is no evidence for the presence of respirable fibers during the processing of carbon fibers or their composites in an actual occupational setting.

The World Health Organization (WHO) defines respirable fibers as fibers > 5 µm long, < 3 µm wide and with a length:width ratio of > 3:1 (WHO 1997). The fiber dimensions established in the 1960s to characterize asbestos fibers are often used to define the fibers that should be counted for occupational safety. Evidence suggests that not only asbestos but other long, thin and durable fibers have the potential to cause cancer (Stanton and Wrench 1972). Especially, Stanton fibers, which are fibers with length > 8 µm and diameter ≤ 0.25 µm have the most carcinogenic power (IARC 2002). Carbon fibers are also durable fiber, and the toxicity of these fibers depends on their morphology (shape and sizes) and rigidity.

In the present research work, we collected debris (micro-particles) generated from CFRP during various machining processes, before being locally exhausted in a CFRP processing factory. We used a scanning electron microscope (SEM) and determined the shape and size of the micro-particles present in these debris.

The occupational safety and health administration (OSHA) permissible exposure limit (PEL) for respirable asbestos is an airborne concentration of asbestos in excess of 0.1 f/cc (fiber/cm^3) as an 8 h time-weighted average (TWA) (OSHA 2002). Furthermore, workers must not be exposed to an airborne concentration of asbestos in excess of 1 f/cc as averaged over a sampling period of 30 min (OSHA 2002). Moreover, the American Conference of Governmental and Industrial Hygienists' threshold limit value (ACGIH TLV) for exposure to refractory ceramic fibers (synthetic mineral fibers) is 0.2 f/cc (ACGIH 2005). In Japan, the Occupational Safety and Health Law has not yet set guidelines regarding the safety levels of synthetic vitreous fibers, man-made mineral fibers, in the workplace (JMHLW 2003). However, the administrative level has been set at 0.3 fibers/cm^3 for ≥ 5 µm long refractory ceramic fibers, and 0.15 fibers/cm^3 for > 5 µm long asbestos fibers (JMHLW 2008, 2017). In addition, article 16–2 of Regulation for Enforcement of the Air Pollution Control Act limits asbestos concentration in the atmosphere to < 10 f/L in factories and workplaces that handle asbestos (OMHW 1971). In the present study, we also applied the asbestos monitoring bylaws to quantify the respirable fiber exposure levels in industrial dust collected from ambient air in the vicinity to the sites of various CFRP machineries, under standard working conditions in the same factory.

Methods

Study factory

This study examined CFRP debris collected from a processing factory located in Japan. The factory site is approximately 55 × 27 m, with the factory building occupying 30 × 21 m, with the main work area inside the factory measuring approximately 30 × 15 m (Fig. 1). The machines that release the debris are partitioned within the factory with plastic curtains or set up in an individual room. A local exhaust ventilation system is installed at the places processing CFRP composite materials under dry conditions. In this study, we collected debris from CFRP manufacturing for analysis by SEM on July 23 and 24, 2018. Furthermore, we carried out exposure assessment of respirable fibers from

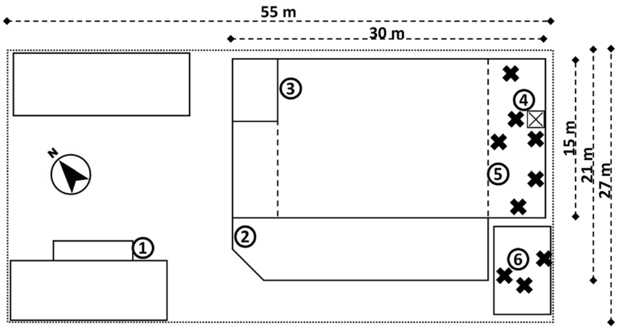

Fig. 1 A sketch drawing of CFRP composite materials processing factory. ✖ Illustration diagram of the factory premises and sites of released debris (sites of cutting and grinding processing of CFRP composite materials); ○ [#1, 2, 3, 4, 5 and 6]: Sampling sites according to asbestos monitoring manual version 4.1; ⊠ Local exhaust ventilation system; *Dashed lines* plastic curtains, *Solid lines* factory building borders, Dotted line land site borders

CFRP under the standard working conditions on November 18–20, 2019.

The CFRP are supplied in the forms of TORAYCA® prepreg (Toray Industries, Tokyo, Japan), and the composite materials consisted of carbon fibers and epoxy thermoset polymer (resin). The carbon fiber content of the TORAYCA CFRP is 67%. In the carbon fiber used, the tensile strength is 500 kgf/mm^2, the tensile modulus is 23.5 tf/mm^2, the density is 1.80, and the fiber diameter is 7 µm. The molded CFRP pipes are mainly 3 m long and 8 cm in diameter, with a thickness of more than 5 mm of the prepreg laminated. The cutting process involves the use of a grindstone cutter (Redibon-Cut RC, Nippon Resibon, Osaka, Japan) to cut the CFRP pipe. It is a circular cutter constructed of a mixture of resinoids and iris, and is mainly composed of aluminum oxide. To cut the CFRP pipe, a diamond cutter was also used (PU Cutter for marble FX-4001; Naniwa Abrasive, Osaka, Japan), which is a circular cutter made of polycrystalline diamond (PCD) tool. The process of grinding also involves the use of various grades of sandpapers, and the most common type of sandpaper was made of aluminum oxide, a widely used abrasive material. To turn the CFRP pipes, a diamond turning insert (DNMX 430.5-DA1000, Sumitomo Electric Industries, Osaka, Japan) was used, which is a pitch circle diameter tool for turning only. A local dust collector exhaust ventilation system with manual filter dust shaking function (model SDC-3700-BS, Suiden, Osaka, Japan) was operational during the cutting and grinding processes of CFRP composite materials.

Analysis of CFRP debris by scanning electron microscopy

The CFRP debris (micro-particles) were collected on 25 mm diameter, 0.8 µm pore size, Nuclepore™ Track-Etched Polycarbonate Membrane Filter (GE Healthcare, Buckinghamshire, UK) mounted on 25-mm In-line filter holder (Pall, Portsmouth, UK) with a minipump (model MP-Σ300N, Sibata Scientific Technology, Saitama, Japan) set at a flow rate of 1.0 L/min from the vicinity to the generation source. The filter holder was placed in front of the exhaust port of the local exhaust system and the micro-particles were collected before being exhausted locally. The filter-collected CFRP micro-particles were fixed on a sample holder with carbon adhesive tape for SEM (Nisshin EM, Tokyo, Japan) and were treated with gold coating by Twin Coater JEC-550 (JEOL, Tokyo, Japan). The collected CFRP micro-particles were examined by SEM and analyzed with EDS using SEM JSM-6010PLUS/LA (JEOL). The analysis included the determination of the morphological properties of the micro-particles (length, diameter, and aspect ratio = length/diameter) based on examination at magnification from 500 to 5000 times. Furthermore, the chemical composition of the microparticles was analyzed by EDS.

Assessment of exposure to respirable CFRP fibers in an occupational setting

Assessment of exposure to respirable CFRP fibers under standard working conditions in this factory was conducted according to the asbestos monitoring manual version 4.1 issued by the Japan Ministry of the Environment to confirm the occupational safety of the factory. Respirable fibers were collected at a height of around 1.5 m from the floor on three occasions, each for 240 min at a flow rate 10 L/min using a low volume pump (model LV-40BW, Sibata Scientific Technology) from six sampling sites during the daytime work of the factory (Fig. 1). The respirable fibers were collected on 47 mm diameter, 0.8 µm pore size, polycarbonate PCTE membrane filter (Advantec MFS, Dublin, CA) on a filter holder with a hood used for asbestos (Sibata Scientific Technology). The CFRP fiber sample collected on the filter was fixed on a sample holder with carbon adhesive tape and then treated with gold coating by Twin Coater JEC-550. The number of respirable fibers on the filter was counted under SEM JSM-6010PLUS/LA in 30 fields of view at × 500 magnification since we confirmed that all of the respirable fibers with aspect ratio more than 3 detected at × 2000 magnification could be also detected at × 500 magnification. Included in the counting were respirable fibers specified by the asbestos monitoring manual version 4.1, measuring > 5 µm long with a diameter < 3 µm, and aspect ratio ≥ 3. The above criteria are almost the same as those used by the WHO and include fibrous substances other than carbon fibers. The geometric mean values of the detected CFRP respirable fibers in the occupational setting were determined from three measurements at each factory site. When respirable fibers were not detected, the default value of 0.30 fibers, the limit of detection (LOD), was used for the calculation of geometric means.

Results

Characteristics of CFRP debris

This study examined CFRP debris collected from a processing factory located in Japan. A sketch drawing of the factory building is shown in Fig. 1. CFRP debris (microparticles) were generated through the processes of CFRP pipe cutting (by the grindstone and diamond cutters), grinding CFRP pipes (using a variety of sandpapers) and turning the CFRP pipes (using the diamond turning insert). The collected CFRP debris generated by the process of CFRP pipe cutting with the grindstone were analyzed by

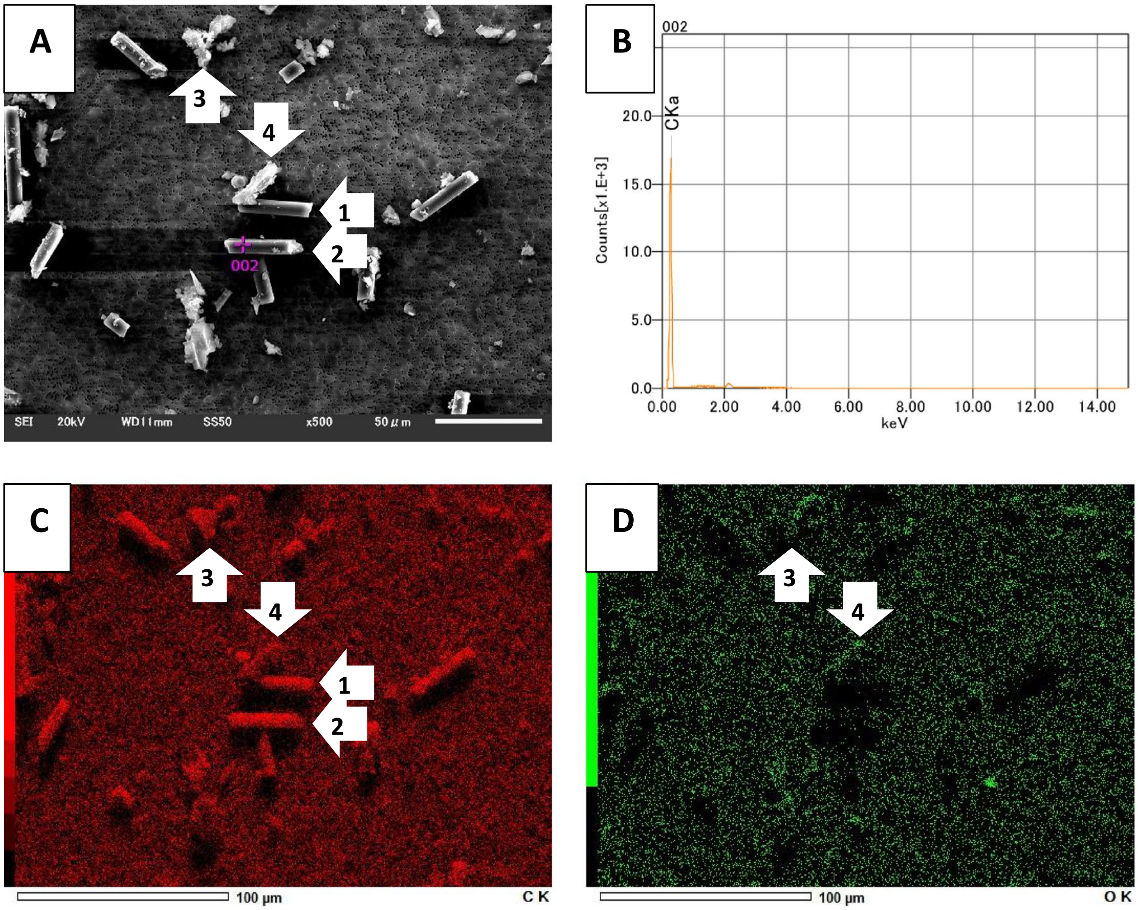

Fig. 2 Analysis of CFRP debris generated by cutting CFRP pipes with grindstone cutter. The released CFRP debris were analyzed by SEM with EDS at magnification × 500. **A** Secondary electron image; **B** Spectrum of EDS point analysis (+: focal point in A); **C** Carbon element map; **D** Oxygen element map. Arrows 1 and 2: Cylindrical fibers from CFRP; 3 and 4: Collapsed object from CFRP

SEM (Fig. 2). Many of the observed debris were cylindrical in shape with a diameter of about 7 µm, which was comparable to the diameter of the original carbon fibers, suggesting transverse break against the longitudinal direction of the fiber (Fig. 2A). The spectrum of energy dispersive spectroscopy (EDS) point analysis of the cylindrical fiber showed that it was made of carbon (Fig. 2B), indicating that the cylindrical fibers were CFRP carbon fibers.

Next, we examined the carbon and oxygen element maps of CFRP debris. The CFRP cylindrical fibers were found in the carbon element map (Fig. 2C, arrows 1 and 2), but not in the oxygen element map (Fig. 2D), probably because it is composed of pure carbon. However, other irregularly shaped objects were faintly colored in the carbon element map (Fig. 2C, arrows 3 and 4) whereas they were vaguely evident in the oxygen element map (Fig. 2D, arrows 3 and 4). These objects are probably breakdown elements of the epoxy thermoset polymer (resin) in CFRP.

Morphological analysis of CFRP debris

Figure 3 shows examples of the CFRP debris examined under the SEM. Morphological analysis indicated that some of these CFRP micro-particles fulfilled the WHO definition of respirable fibers, i.e.; > 5 µm long with a diameter of < 3 µm and aspect ratio of ≥ 3.

Representative CFRP debris collected near the grindstone cutter are shown in Panels A and A’ of Fig. 3. Most of the CFRP micro-particles were relatively large-sized cylindrical fibers and irregularly shaped objects. However, we also found respirable fibers (15.5 µm long, with 2.36 µm diameter and aspect ratio of 6.62, arrow 1 in Fig. 3).

The CFRP debris collected near the diamond cutter are shown in Panels B and B’ of Fig. 3. The carbon fibers were Y-shaped but matched the definition of respirable fibers. The representative respirable fiber shown in Fig. 3 (arrow 2) was 19.0 µm long with 2.83 µm diameter and aspect ratio 6.73.

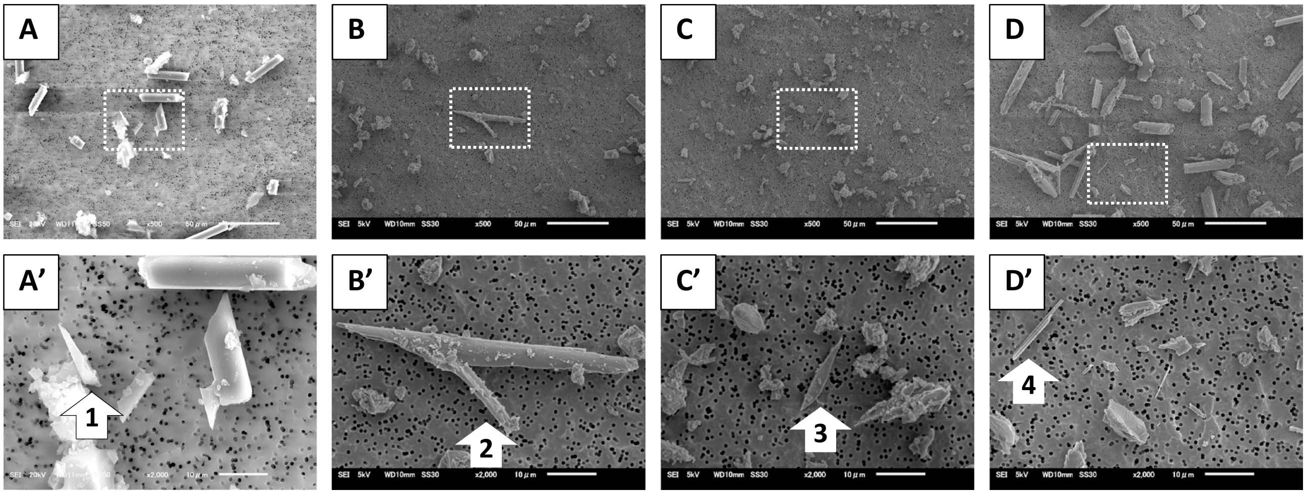

Fig. 3 Morphological analysis of CFRP debris components generated by various processes. CFRP debris were generated by the process of cutting CFRP pipes with grindstone cutter (**A** and **A’**) and diamond cutter (**B** and **B’**) and by the process of grinding of CFRP pipes using various types of sandpaper (**C** and **C’**) and diamond turning insert (**D** and **D’**). Top panels were examined by SEM at magnification × 500. The dotted squares on the top panels indicate the position where the images on the bottom panels were taken. Bottom panels were examined at magnification × 2,000. Arrows 1, 2, 3 and 4: respirable fibers, as defined by WHO

The structures suggesting the adhesion of breakdown elements of the epoxy resin to the fragment of carbon fiber were observed, although it is possible that breakdown elements of epoxy resin were localized in proximity to the fragments of carbon fiber after being collected on the filter.

Panels C and C’ of Fig. 3 show representative debris collected near the CFRP pipes after surface smoothing with sandpaper. Most of the CFRP micro-particles were fine particles and a mixture of carbon fibers and resin. However, we also found micro-particles that matched the definition of respirable fibers (17.4 µm long with 2.82 µm diameter and aspect ratio of 6.17 (Arrow 3, Fig. 3).

Panels D and D’ of Fig. 3 show representative CFRP debris collected from around the CFRP pipes after being turned with the diamond turning insert. Most of the micro-particles were fragments of cylindrical fibers that resembled in size the original carbon fibers. However, we also found micro-particles that matched the definition of respirable fibers (16.0 µm long with 1.25 µm diameter and aspect ratio of 12.8 (Arrow 4, Fig. 3). Interestingly, CFRP debris collected from the same site contained extremely thin filaments. The two representative filaments shown in Fig. 4 were 7.60 µm long with 0.31 µm diameter and aspect ratio 24.5 (arrow 1, Fig. 4), while the respective measures of the other filament (arrow 2, Fig. 4) were 9.49 µm, 0.40 µm, and 23.7.

Assessment of occupational exposure to CFRP respirable fibers

First, we measured the concentration of respirable fibers at the six sampling sites illustrated in Fig. 1 using the asbestos monitoring manual version 4.1 by the Japan Ministry of the Environment to establish the factory occupational safety. The concentration ranges of respirable fibers (fibers/liter [f/L]) were 0.9–3.9 f/L at site 1 (factory premises, geometric mean 1.3 f/L), 0.3–5.4 f/L at site 2 (factory entrance,

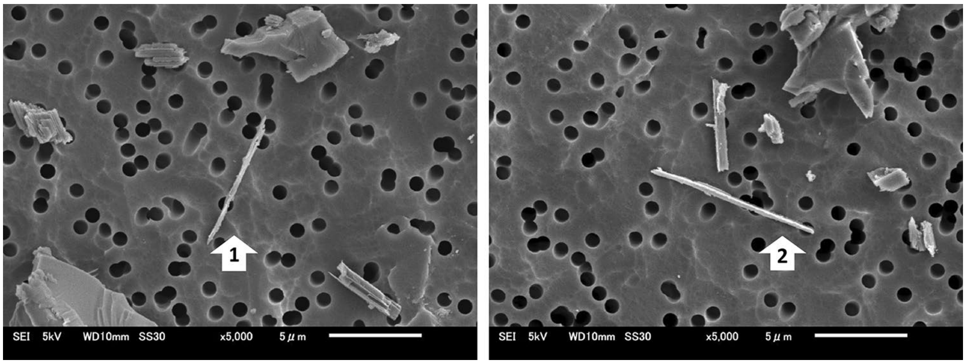

Fig. 4 Morphological analysis of ultra-thin fibrous substances generated from CFRP composite materials. The ultra-thin fibrous substances contained in CFRP debris were generated by the process of grinding of CFRP pipes using diamond turning insert. The ultra-thin fibrous substances were identified by SEM. Magnification × 5,000. Arrows 1 and 2: respirable fibers, as defined by WHO

Table 1 Assessment of exposure to CFRP respirable fibers in an occupational setting

Sampling site No	Factory location	Concentration of respirable fibers [fibers/L]				
		Day 1	Day 2	Day 3	GM	GSD
1	Premises	0.9	3.9	0.6	1.3	2.7
2	Entrance	0.3	5.4	1.8	1.4	4.3
3	Factory interior	3.3	4.2	2.7	3.3	1.2
4	Near the places of processing	6	6.9	12.7	8.1	1.5
5	Near the places of processing	3	4.2	2.7	3.2	1.3
6	Near the places of processing	5.6	3.2	5.3	4.6	1.4

Data are concentrations of respirable fibers in samples collected from the six sampling sites marked in Fig. 1 *GM* geometric mean, *GSD* geometric standard deviation

geometric mean 1.4 f/L) (Table 1). On average over the three days, the concentration ranges of respirable fibers at the factory premises and factory entrance areas had similarly low levels. However, since the entrance was where exposed workers go in and out during work, the entrance might be contaminated with fibers released from the workers and the variation might be greater depending on how often the entrance was used. The concentration ranges of respirable fibers were 2.7–4.2 f/L at site 3 (factory interior, geometric mean 3.3 f/L), 6.0–12.7 f/L at site 4 (geometric mean 8.1 f/L), 2.7–4.2 f/L at site 5 (geometric mean 3.2 f/L) and 3.2–5.6 f/L at site 6 (geometric mean 4.6 f/L) within the factory near the sites of CFRP grinding and cutting (Table 1).

Discussion

The present study investigated the nature and safety of ultrastructure of debris collected during factory processing and manufacturing of PAN-based CFRP. We found potentially dangerous respirable fibers with a high aspect ratio, which was generated during the processing of PAN-based CFRP. Under standard working conditions in the same factory, the concentrations of respirable fibers at the six examined factory areas were below the standard limit of 10 fibers/L, specified for asbestos dust-generating facilities under the Air Pollution Control Law in Japan. This finding indicates that the regular risk assessment of carbon fiber debris is necessary to ensure work environment safety.

In the case of PAN-based CFRP, the debris generated during conventional machine processing are considered safe because carbon fibers break predominantly transversely to the fiber's major axis, whereas respirable particles are experimentally released from pitch-based CFRP during machine processing (Kehren et al. 2019; Wang et al. 2017). In addition, the micro-particles of respirable fibrous fragments of the PAN-based CFRP are predominantly agglomerates, consisting of the resin matrix and granular-shaped fiber fragments that appear to be loosely attached to each other in the experiment (Kehren et al. 2019). Moreover, standard mutagenicity tests conducted previously on PAN-based carbon fibers were negative and an ongoing survey of workers in a carbon-fiber production plant showed no pulmonary function abnormalities and no evidence of dust-related lung diseases (OSHA 2021). However, others have reported that CFRP cables subjected to high-energy tensile tests until rupture release respirable fibers with diameters smaller than the original carbon fibers (Schlagenhauf et al. 2015). Similar findings have been reported in tests involving composite material of carbon nanotubes and CFRP (Bello et al. 2009, 2010). In such a case, based on the hypothesis of fiber pathogenicity (Stanton and Wrench 1972; Pott 1978), caution is required for a possible release of respirable fibers smaller than their original diameter. Based on the above background, the aim of this study was to determine the components and morphology of debris material collected from CFRP processing at the factory work site.

Many of the collected carbon fibers were the original carbon fibers cut transversely to the fiber's major axis, a finding similar to those of previous studies (Kehren et al. 2019; Wang et al. 2017). However, we also confirmed the presence of respirable carbon fiber fragments, and by collecting samples from different areas of CFRP machine processing, we confirmed the release of such material under all steps of the machine processing, including cutting with the grindstone cutter, cutting with the diamond cutter, grinding using sandpapers, and turning with a diamond turning insert. Among the previous papers investigating similar topics to the present study, Lovreglio et al. (2020) used SEM with filter-based air sampling for carbon fiber reinforced and Methner et al. (2012) used direct reading instruments and TEM with filter-based air sampling for carbon nanofibers, while we used direct reading instruments and SEM with filter-based sampling. Therefore, it is difficult to distinguish those studies and ours by the method, but we show the difference by describing the main results of the above studies.

In this study, the machine processes that yielded respirable fibers were all dry water-free processes. It has been reported that dry machining contributes to the material damage and increases the tools wear rate, in addition to the release into the air of fine dust of ultra-small sharp-edged particles (Ramulu and Kramlich 2004). Debris formation from CFRP, including fibrous debris formation of small-diameter particles, has been studied extensively in laboratory settings in the past (Aamir et al. 2019; Caggiano et al. 2018; Girot et al. 2009; Haddad et al. 2014) It is known that sharp tools, especially polycrystalline diamond (PCD), are more likely to produce smaller (respirable) dust due to their characteristic small cutting edge radius (Nguyen-Dinh et al. 2018). In our study, fine fibrous debris were found, especially in the turning process that included the use of a turning insert equipped with a PCD. During the turning process, two factors can affect the debris morphology: depth of the cut and fiber orientation (angle θ), but the latter is known to play a dominant role, although the debris morphology also depends on the depth of cut when the fiber angle is 0◦ and it becomes fine powder when the depth of cut is small (0.1 mm) (Li et al. 2016). The fine fibrous debris in our analysis of material collected from the turning process site was thin fibrous material (respirable fibers). Although the definite depth in our study is unknown due to the manual work of the operator, we believe it originate when the diamond turning insert teeth introduced shallowly from the side against the original carbon fibers.

Our analysis confirmed the production of respirable fibers with a high aspect ratio from PAN-based CFRP by sample collection from pre-defined areas in the factory. It has been reported that excessive exposure to respirable fibers, such as Stanton fibers, can potentially cause cancer (Morfeld et al. 2015; Paris et al. 2017). Exposure to respirable pitch carbon fibers by inhalation produced dose-dependent and transient inflammatory responses in the lungs of rats (Warheit et al. 1994). Other respirable fibers have also been reported to induce inflammation and tissue remodeling in the rat lung and cause genotoxic potential and carcinogenic effects (Borm et al. 2018; Cui et al. 2019). Therefore, we assessed the concentration of respirable fibers under standard working conditions in a factory. Since most of the real-time monitoring devices cannot distinguish respirable fibers (Asbach et al. 2017; Kehren et al. 2019), it is necessary to use a method that allows direct sampling of respirable fibers into filters followed by manual counting under SEM (Scarselli et al. 2016). Underestimation of the actual fiber number can lead to a false assessment of the safety of workplace handling of processing fibers and fiber-containing materials. Thus, the respirable fibers were measured in the present study referring to the asbestos monitoring manual version 4.1 issued by the Japan Ministry of the Environment to confirm occupational safety. The manual says that the total number of fibers should be counted by phase-contrast microscopy at × 400 magnification, and if the total number of fibers exceeds 1 f/L, asbestos should be identified and counted by SEM. Although the observation at × 1000- × 2000 magnification for SEM is recommended, the manual allows counting at a lower magnification that can definitely detect fibers of 0.2 µm. Therefore, the number of respirable fiber was counted at × 500 magnification in the present study. This manual adopts the WHO policy of recommending counting the number of respirable fibers and is the standard method of evaluation applied in Japan.

The smallest numbers of respirable fibers were found outside the factory premises and at the entrance to the factory. This was probably because these areas of the factory were isolated from the processing area. In contrast, the highest number of fibers was detected at the processing site where the majority of respirable fibers was generated and most work was conducted, near the dust collector. In the same factory, slightly more respirable fibers were detected in certain areas inside than outside the factory, although they were isolated from the processing sites with plastic curtains. Under standard working conditions where the dust collector was operating, the respirable fiber counts at all points measured in this factory were below the site boundary standard of 10 fibers/liter for specified dust (asbestos) generating facilities under the Air Pollution Control Law. Based on the results of our survey, we concluded that the distribution of respirable fibrous materials at the sites of manufacturing and processing of CFRP at the subject plant was at a safe level under the usual working conditions. In this regard, Schlagenhauf et al. reported the release of respirable fibers following cable failure (the measured peak fiber concentration was 0.76 fibers/cm^3) while the overall fiber concentration of 0.07 fibers/cm^3 in the control room was below 0.1 fibers/cm^3, the permissible exposure limit (PEL) as well as the ACGIH's threshold limit value (TLV) for asbestos. Their results were considered to be due to the fast and effective ventilation system installed in the working place. Our survey confirmed the use of an effective and operational exhaust ventilation system (model SDC-3700-BS) at the site of CFRP processing. As a result, the factory had a low level of respirable fibers in the occupational setting. In the case of a plastic composite material containing carbon nanofibers, it has been reported that improperly designed, maintained, or installed engineering controls may not be completely effective in controlling releases of carbon nanofibers (Methner et al. 2012). Therefore, it is necessary to regularly assess the work environment at the processing site of CFRP factory.

Conclusions

Using interventive sample collection procedure and SEM, we confirmed the presence of potentially dangerous respirable fibers with a high aspect ratio, which was generated during the processing of PAN-based CFRP. Furthermore, using the most stringent regulatory assessment protocol for asbestos monitoring applied in Japan, we confirm that the factory building/workshop design and the installed ventilation/exhaust system maintained the level of respirable fibers below the permissible exposure limits. The results of this survey point to the importance of effective exhaust systems to ensure work environment safety, and that exposure assessment must be conducted at each carbon fiber processing factory.

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Data availability Data are available upon reasonable request.

Declarations

Conflict of interest All authors declare no conflict of interest.

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