

OCCUPATIONAL HEALTH PROBLEMS ASSOCIATED WITH THE FIBREGLASS-REINFORCED PLASTIC INDUSTRY

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ABSTRACT

The demand for fibreglass-reinforced plastic (FRP) has increased progressively and in many fields its use has replaced asbestos. FRP is a composite material comprising glass fibres embedded in a resin. Because of its strength, light weight and durability, it has many uses, among others, the production of textiles, aircraft, automobiles, bath tubs, enclosures, boats and ships. FRP manufacturing requires embedding of the glass fibres in a resin which may contain organic solvents such as methyl ethyl ketone peroxide (MEK) and styrene, known neurotoxins which contribute to several health problems.

Commonly observed health conditions among workers in the FRP industry include cancers, and skin, respiratory and neurobehavioural symptoms, as the employees are exposed to a wide variety of hazards (chemical, physical and ergonomic). This case report highlights the causal agents associated with contact dermatitis in a FRP laminator. Clinical evaluation and a careful history were supplemented by a workplace visit and patch testing. Although exposed to many hazardous substances, this worker was allergic to the components used in manufacturing the rubber gloves given as personal protective equipment (PPE). This emphasises the important contribution of PPE to occupational dermatoses.

CASE REPORT

A 38-year-old female laminator in the FRP boat building industry presented to the workplace occupational health clinic with a two-year history of an itchy rash on both hands. There was no past medical history of allergies and no history of atopy, in particular, no eczema or asthma. She had a background history of hypertension controlled by one hydrochlorothiazide daily. She is a single parent supporting one child.

She had worked as a laminator for the past 12 years. The laminating process involves the gradual build-up of layers of woven glass-fibre material impregnated with resin matrix in a mould. The resin is worked into each layer of glass fibre with a roller. Because of hazardous chemicals in the resin (styrene active diluent) and the hardener, MEK peroxide, laminators wear natural-rubber latex gloves for most of the working day. A laminator uses up to three pairs of gloves per day, because when working with a resin and fibreglass, these substances adhere to the gloves and damage them by making them hard. If small particles adhere to gloves, these are removed with acetone and the gloves are re-used. However, this shortens the life of gloves which means the gloves must be replaced more

often. The patient related the onset of her rash to the use of latex gloves. Two years after the start of her skin rash, she was seen by the occupational health nurse at her work with itch, swelling of her face and neck, and red eyes. She was referred to a local hospital and diagnosed with 'latex' allergy. The work arranged for her to get nitrile gloves with cotton inners (see Figure 1), and for some time she had no skin rash.

However, nitrile gloves were sometimes not available in the factory, and when she returned to wearing latex gloves, her skin rash would flare up again.

When we saw the patient at the occupational skin clinic, she had used latex gloves for three days and the rash on her hands had flared. Scaly erythematous plaques, lichenification and excoriations were evident on the dorsum of the hands (see Figure 2). The palms were spared. There were no acute lesions at the time of examination, but these had been present previously. The rest of her skin was normal. The pattern of dermatitis noted in this laminator is classic for a glove-allergic contact dermatitis which typically involves the dorsum of the hands (see Figure 2).

ideal for use in aerospace, wind-generator, marine and automotive industry constructions.

The UP resin matrix used by the patient, includes a base resin (UP), styrene and auxiliary chemicals. Styrene is an essential reactive diluent which thins the resin making it easier to incorporate into the fibreglass during the laminating process. As a reactive diluent it is chemically incorporated into the final plastic as a polymer cross-linking agent and thus does not need removal from the final composite.³ Auxiliary ingredients include accelerators, inhibitors, hardeners, catalysts and a variety of pigments. Most of the industry uses MEK peroxide as a hardener and cobalt naphthenate or diethylaniline as an accelerator. Furthermore, acetone is used for cleaning purposes.⁴ Workers in the FRP industry are heavily exposed to fibreglass particles, styrene, uncured resin and MEK peroxide.

SKIN DISEASES

One of the commonest health effects in the FRP industry is occupational skin disease. Irritant contact dermatitis (ICD) is more common than allergic contact dermatitis (ACD).⁵ Epidemiological studies conducted in various factories manufacturing FRP have reported the prevalence of occupational dermatoses in the industry as 62.45% in wind-turbine industries followed by 58.85% in factories making boats and tanks.⁶

A 1993 survey of 100 workers (86 from the FRP industry, 11 from the polystyrene production industry and three from polyester resin-coating manufacture) reported that 26% (22/86) of the FRP workers had occupational dermatoses. Most were mild with only three workers requiring sick leave. ICD accounted for 12 cases, four were due to accidental injuries and six had ACD. The ACD was due to natural rubber in gloves ($n = 4$), phenol-formaldehyde resin ($n = 1$) and cobalt naphthenate ($n = 1$). ICD was caused by the dust and mechanical friction of clothes ($n = 7$). Irritant hand dermatitis was caused by the combined hazards of unsaturated polyester or vinyl ester resins, fibreglass, organic solvents and dust from finishing work ($n = 5$).⁷

A Japanese survey examined skin problems in 148 workers from 11 small to medium-sized FRP industries exposed to unsaturated polyester resins and a variety of auxiliary agents including styrene. Skin problems (itch and dermatitis) were reported by 58.8% (87/148) of workers, 17% (25/148) of whom had consulted their doctor. One worker had severe dermatitis and took sick leave.⁴ An interesting finding was the seasonal occurrence of skin problems identified by examination of 67 workers, 23.3% were documented with skin problems in summer and 13.4% in winter.

A Spanish study reported on ten workers with suspected dermatitis attending an occupational health clinic, who were employed in the wind-energy industry. Materials used in the



Figure 1: Nitrile glove used to replace natural rubber later ones.

construction of the wind-turbine blades include epoxy resin (bisphenol) and curing agents strengthened by glass fibre. Five workers (5/10) were diagnosed with ACD to epoxy resin. The diagnosis of the remaining five workers (5/10) was ICD.⁴

These studies were significant in demonstrating that multiple exposures can cause skin diseases.

RESPIRATORY DISEASES

Another important health effect in FRP industries is respiratory disease. A National Institute for Occupational Safety and Health (NIOSH) cohort study conducted in Washington State between 1959 and 1978 among styrene-exposed workers in the FRP boat-building industry reported an overall mortality of 598 deaths (standardised mortality ratio (SMR) = 0.96, CI 0.89–1.04), including non-significant excess mortality from lung cancer (SMR = 1.23, CI 0.95–1.56) and chronic obstructive pulmonary disease (COPD) (SMR = 1.15, CI 0.81–1.58). COPD mortality increased two-fold (SMR = 2.02, CI 1.08–3.46) among 580 workers with potential high-styrene exposure.⁸

She responded well to highly potent topical steroids and emollients, but the rash recurred as soon as she started using latex gloves.

A walk through of the laminating, painting, moulding, assembly and joinery areas was undertaken. The moulding and lamination took place in a large open, well-ventilated shed. Laminators applied fibreglass sheets and resin manually to preformed gel-coated moulds in a bending or kneeling position for most of the day, often positioned on top of the structure under construction. Exposure to uncured resin and additives was thus unavoidable. The workers were provided with PEP including respirators, disposable overalls and gloves which were variably used. Some workers wear their own clothes which are presumably washed at home, a potential hazard for family. The laminators wore natural-rubber latex gloves for most of the working day and needed to change them regularly due to damage and contamination. Several hazardous substances (see Table I) and exposures were identified.

In accordance with the International Contact Dermatitis Research Group Guidelines (ICDRG),¹ a patch test was performed using a standard battery of 45 commercially available common allergens applied in Finn chambers. The allergens included rubber additives, fragrances, formaldehyde, formaldehyde-releasing preservatives and some dyes and resins. Because of the classic pattern of the dermatitis – supported by her dermatitis history – a glove-allergic contact dermatitis seemed the most likely diagnosis and none of the hazardous substances identified during the work visit were incorporated in the initial patch testing. The patch tests were removed after 48 hours occlusion and the results were read 24 hours later. A strong (2+) positive reaction was noted for thiuram mix and carba mix (both rubber allergens supporting glove dermatitis), nickel sulphate and paraben mix. A weak positive reaction was noted for cobalt chloride (1+). The remaining allergens, including epoxy, tested negative.

EPIDEMIOLOGY OF OCCUPATIONAL DISEASE IN THE FRP INDUSTRY

Global demand for FRP has grown rapidly in the past 30 years and is expected to continue to grow in the future.² Production capacity has increased significantly at an annual growth rate of 33% between 2002 and 2006. Worldwide



Figure 2: Scaly erythematous plaques, lichenification, and excoriations of the dorsum of the left hand with excoriated vesicopapules on the thumb border and 1st webspace.

production of FRP was approximately 4.2 million tons in 2007, whereas demand was 4.5 million tons. In China alone, the production of FRP was 38.1% of the global FRP production.² Unfortunately, there is little information about the South African FRP industry.

FRP is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass ('fibreglass'), carbon, aramid (aromatic polyamide) or basalt. Fibres such as paper, wood or asbestos are rarely used. The polymer is usually an epoxy, vinyl ester, unsaturated polyester or rarely phenol formaldehyde resin derivative. When combined with agents to enhance or alter the material properties of the polymer, the polymer is known as a 'plastic'. Composite plastics refer to plastics that result from bonding two or more materials with different material properties to achieve a final product with specific characteristics. Fibre-reinforced plastics are a category of composite plastics that specifically use fibre materials to mechanically enhance the strength and elasticity of the plastic. The extent that strength and elasticity are enhanced in a fibre-reinforced plastic depends on the mechanical properties of both the fibre and matrix, their volume relative to one another, and the fibre length and orientation within the matrix. Reinforcement of the matrix occurs when the FRP material exhibits increased strength or elasticity relative to the strength and elasticity of the matrix alone. The fibrous material is bonded with the matrix during moulding. FRP moulding begins by placing the fibre on, or in, a mould. Dry fibres are 'wet' with resin and then cured, leaving the matrix and fibres in the shape created by the mould.

The composite materials are stable, strong, light and impervious to sound, solvents and water making them

TABLE I: THE MAIN ALLERGENS AND IRRITANTS IDENTIFIED IN THE PATIENT'S WORKPLACE

SUBSTANCE	MODE OF ACTION
Glass fibre (reinforcing fibre)	Irritant
Styrene (active solvent diluent and cross-linking agent)	Irritant and type I and IV Allergen
Methyl ethyl ketone (MEK) peroxide	Irritant and type IV allergen
Cobalt naphthenate (auxiliary agent)	Irritant and type IV allergen
Acetone (solvent used for cleaning)	Irritant
Unsaturated polyester resin (UP)	Potent type I and IV allergen
Natural rubber latex (PPE gloves)	Type I and IV allergen

A literature review, analysing 55 articles from industries using styrene, identified ten case reports of obliterative bronchiolitis, eight of occupational asthma and four of chronic dyspnoea. Thirteen (87%) of 15 cross-sectional studies of workers provided evidence of an association between styrene exposure and airflow limitation. Furthermore, six out of nine mortality studies found excess COPD-related mortality.⁹

CANCERS

According to the International Agency for Research on Cancer (IARC), styrene is classified as possibly carcinogenic in humans and experimental animals.¹⁰

Various cancers have been associated with exposure to FRP. One Danish study followed 36 610 workers of FRP industries, mostly involving boat-building and hand-lamination techniques, and 14 293 workers not exposed to styrene between 1970 and 1990. A standardised incidence ratio (SIR) of 3.16 (95% CI 1.03–7.39) for cancer of the salivary glands was reported for employees exposed to styrene from the 1960s. Compared to workers not exposed to styrene, workers in the FRP industry with the highest exposure probability had a statistically significant two-fold increased incidence of pancreatic cancer.¹¹

Among the 598 deaths recorded for styrene-exposed workers in the FRP boat-building industry reported in the National Institute for Occupational Safety and Health (NIOSH) mortality cohort study, excess lung (SMR = 1.23, CI 0.95–1.56) and ovarian cancer (SMR = 3.08, CI 1.00–7.19) were recorded.⁴

A retrospective cohort study extended the study period of the NIOSH mortality cohort of workers at two FRP boat-building plants between 1959 and 1978. Overall, 860 deaths occurred among 5 204 employees (SMR = 1.09, CI 1.02–1.17) with excess mortality for oesophageal cancer (SMR = 2.30, CI 1.19–4.02, *n* = 12) and prostate cancer (SMR = 1.71, CI 1.09–2.54, *n* = 24). They also showed a higher incidence of urinary tract cancer (SMR = 3.44, CI 1.26–7.50, *n* = 6) among 2 062 highly exposed workers, which increased with duration of employment.¹²

NEUROBEHAVIORAL EFFECTS

Exposure to substances in FRP industries can result in several neurobehavioural effects.

A study done in the boat-building industry in Finland demonstrated that the laminators who were exposed to high levels of styrene had worse postural stability than non-laminators and the impairment was witnessed at a younger age (less than 50 years).¹³

In 1989, a Belgium cross-sectional study of workers was performed three years after the closure of a FRP polyester boat-building plant. The study found that most complaints

disappeared after the end of exposure, although abnormal equilibrium and reduced sense of smell persisted in previously exposed workers (*p* ≤ 0.05). These results suggest that at an average concentration of 155 mg/m³ of exposure to atmospheric styrene for less than ten years may result in persistent neurotoxic effects.¹⁴

ALLERGENS IN THE FRP INDUSTRY

Sensitisation prevalence to substances used in the FRP industry is increasing among workers.^{5–7} Specific substances and chemicals are recognised as allergens in the FRP industry as described in Table II. The most common causes of ACD are epoxy resin compounds. Polyurethanes which are well-known causes of asthma, rhinitis and conjunctivitis are also implicated in ACD. Carboxylic acid anhydrides may cause IgE-mediated rhinitis and asthma.⁶

Occupational skin dermatoses among plastic composite industry workers was described in 2% (43/2 178) of workers diagnosed with occupational skin disease attending a tertiary Finnish Occupational Health Service from 1974 to 1993. ACD accounted for 32% (18/43) of those with occupational dermatitis in the FRP industry and was second only to ICD at 49% (21/43). Immunologic contact urticaria accounted for 9% (4/43) of skin diseases. Epoxy accounted for most ACD. Asthma (2 cases) and allergic rhinitis (1 case) caused by exposure to epoxy resin or its hardeners was also reported.⁵

A retrospective Finnish study screened the patch-test results of 4 445 workers from 1991 to 2014 for allergic reactions to various epoxy resins, epoxy hardeners and reactive diluents in their baseline, epoxy compound, and plastic and glues allergen patch-test series. A positive reaction to diglycidyl ether of bisphenol A resin (DGEBA-R) was found in 4.1% (181/4 445) workers. No testing was done in 17 workers with known contact allergy to DGEBA-R. The total number with DGEBA-R was 4.5% (198/4 445). The total number of patients with sensitivity to the epoxy resin system was 5.4% (240/4 445). Thirty-one (13%) of the 240 patients gave no history of exposure to epoxy resin systems leaving 209 (87%) of tested workers diagnosed as occupational contact allergy to epoxy resin products.¹⁵

Most of the chemicals used by employees in FRP product manufacturing, including UP resin, styrene and hardeners have been reported to cause both ACD and ICD.⁴ A case report described a worker in the boat-building industry with occupational hand dermatitis. Patch testing showed one weakly positive (1+) reaction to cobalt-2-ethylhexanoate (used as an accelerator in UP resin). The diagnosis was not clear initially, but after the patient's pruritic rash improved on holiday an occupational dermatoses was strongly suggested. The patch test was repeated with commercial allergens, a selection of his own diluted samples, plus two

TABLE II: COMMON ALLERGENS FROM THE FIBREGLASS INDUSTRY (MODIFIED FROM TARVAINEN AND KANERVA)⁴

INDUSTRIES	ALLERGENS	ALLERGY REACTION
Aircraft-building	DGEBA ER ER amine hardener Non-DGEBA epoxy resin UP resin Chromium (VI) Cyclohexanol peroxide Glass fibre Mold releasers	Type IV Type IV Type IV Type IV Type IV Type IV Types I Types I
Boat-building	ER UP resin Cobalt Phenol formaldehyde resin Natural rubber latex Glass fibre Styrene	Type IV Type IV and Type I Type IV Type IV Type I as CU Types I Types I
Ski and ski poles-building	DGEBA ER ER amine hardener MTHPA Polyester resin Cobalt Glass fibre dust	Type IV and Type I Type IV and Type I Types I Type IV Type IV Types I
Wind-turbine building	DGEBF	Type IV

ER = epoxy resin, DGEBA = diglycidylether of bisphenol-A, DGEBF = diglycidylether of bisphenol-F, UP = unsaturated polyester, MTHPA = methyl-*tert*-hydrophthalic anhydride, CU = contact urticaria

cobalt salts. The tests showed strong allergic reactions to the cobalt salts and a weaker reaction to nickel sulfate.¹⁶

In another case report from the fibreglass-reinforced plastic industry, the worker had positive patch-test reactions to MEK peroxide, benzoyl peroxide, rubber chemicals and cobalt chloride, but not to the polyester resin itself.¹⁷

In Madrid, Spain, a recent descriptive observational study was done between 2009 and 2011 at companies that produced aerogenerators (wind turbines). Ten patients were referred to the dermatology clinic of the National School of Occupational Medicine. Five of ten workers had ACD. Using the standard patch-test series of the Spanish Contact Dermatitis and Skin Allergy Research Group, a positive reaction to epoxy resin (bisphenol A) was reported in four patients, one of them was also sensitised to triethylenetetramine and diethylenetetramine which are curing agents. One patient was sensitised to bisphenol F (epoxy resin).¹⁸

Two field surveys were conducted in 1997 and 1998 in Japan in 11 small to medium-sized FRP factories. Questionnaires and dermatology examinations were completed for 148 workers. Only 20% (29/148) of these workers from two of the original 11 factories were available for a follow-up patch-testing study for various reasons. Patch-test allergens included commercial plastic and glue-series allergens and many in-house preparations of products identified and collected from the two participating factory workplaces. Sensitisation to at least one of the substances tested was

found in 62.1% (18/29) workers, two of whom reported no skin problem. The patch-test results revealed two positive reactions to UP resin, six to cobalt chloride, five to benzoyl peroxide, four to methyl ethyl ketone peroxide, two to para-tertiary butyl catechol, one to styrene, one to formaldehyde and one to glass-fibre dust. Of the 22 workers who experienced skin problems 16 showed a positive reaction to at least one substance tested. After accounting for exposures and dermatitis history, 32% (7/22) workers were diagnosed with pure ACD and 41% (9/22) with ACD and/or mechanical irritation. Irritant dermatitis was diagnosed in 27% (6/22) 3 cases of chemical irritation and three of mechanical irritation.¹⁹

CONCLUSION

The patient discussed in this case report has worked as a FRP laminator for the same company and has been exposed to hazardous substances for more than 12 years. These substances include fibreglass, UP resin, styrene, MEK peroxide and the chemicals used in the manufacture or released during degradation of protective personal equipment. The onset of the hand dermatitis related to glove use and the distribution and pattern of eczema suggested a glove reaction. She demonstrated improvement in symptoms when she changed from latex to nitrile gloves. Despite her obvious exposure to the hazardous substances used in the FRP manual open-moulding lamination process, it was a type-IV delayed hypersensitivity reaction to rubber chemicals present in the PPE issued for her protection that caused her allergy.

The appropriate choice of gloves in any occupational setting is fraught with problems. There is no single glove material that is suitable for all chemical exposures. At best gloves should be worn as 'splash protection' only and changed as soon as they are contaminated or damaged. Natural-rubber latex gloves were chosen for the laminators. While these are readily available and relatively cheap they are not effective barriers to styrene, acetone, UP resin and related compounds. Nitrile, neoprene and butyl gloves offer more effective barriers but have distinct disadvantages especially manual dexterity, availability and cost. Irrespective of the glove material, resin and fibre adheres to the gloves which, with time, hardens and damages the gloves requiring frequent replacement with new ones.

With the increase in demand for FRP in many fields, the occupational health effects are expected to increase. Sensitisation to substances used in the FRP industry is increasing among workers as demonstrated by research described in this case report. Most cases of ACD have been due to UP resin contact in lamination work. Prevention by elimination or minimising the exposure using engineering is the key to controlling the rising prevalence.

DECLARATION OF CONFLICT OF INTEREST

The author declares no conflict of interest.

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