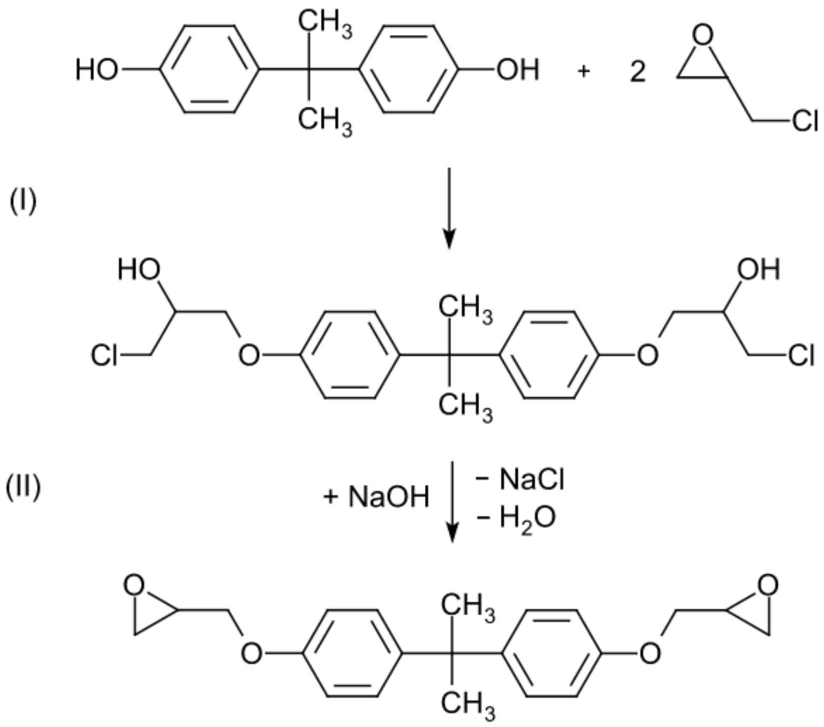

EPOXY IN THE SURFACE COATING INDUSTRY

RESIN SYSTEMS AND HYPERSENSITIVITY

UNIVERSITY OF BERGEN

EPOXY IN THE SURFACE COATING INDUSTRY

RESIN SYSTEMS AND HYPERSENSITIVITY

Linda Aumo, Jorunn Kirkeleit, Bjørg Eli Hollund, Kaja Irgens-Hansen, Magne Bråtveit

CONTENTS

PREFACE

This project has been led by the Research group of Occupational and Environmental Medicine at the Department of Global Public Health and Primary Health Care at the University of Bergen (UiB), while Department of Occupational Medicine, Haukeland University Hospital (HUS) has been an active partner. The project was funded by the Norwegian Research Council under the Research Programme on Welfare, Working Life and Migration (VAM).

<u>Project group:</u>

Project leader/associate professor **Linda Aumo** (PhD, Occupational Hygienist, UiB), work package leader patch testing **Kaja Irgens-Hansen** (PhD, MD/Senior Consultant, Department of Occupational Medicine, HUS), **Bjørg Eli Hollund** (PhD, Certified Occupational Hygienist, HUS/UiB), **Jorunn Kirkeleit** (PhD, Occupational Hygienist, HUS/UiB) and Professor **Magne Bråtveit** (PhD, Occupational Hygienist, UiB).

<u>Scientific collaborators:</u>

Katri Suuronen (PhD, adj. prof, occupational toxicology) at the **Finnish Institute of Occupational Health (FIOH), Helsinki, Finland** is world leading in research on causes of occupational dermal and respiratory diseases and the development of specific diagnostic testing. Contact allergy to epoxy compounds has been an area of special interest at FIOH, and Suuronen and coworkers have tested their patients exposed to epoxy products with epoxy patch test series comprising not only commercial test substances, but also many in-house test substances. The scientific production of the researchers at FIOH formed the basis for our proposal.

Kate Jones is a senior scientist and the group leader of the Biological monitoring Team at the Health and Safety Executive (HSE) Science and Research Center, UK. Her main expertise is within assessment of exposure metrics and analytical chemistry both within air monitoring and specializing in biomonitoring. Jones is also a service manager for biological monitoring analysis at HSE, and undertakes research and method development, particularly human volunteer studies.

Dr Glen McConnachie is a highly experienced scientist within the Analytical Chemistry Team at Health and Safety Executive (HSE) Science and Research Centre, UK. His expertise is analysis of air monitoring and bulk samples for a wide range of organic compounds including diisocyanates, amines, aldehydes and pesticides. He is also involved in the preparation and analysis of samples for the AIR Proficiency Testing scheme. He has extensive experience of method development and incident investigation.

<u>Industry collaborators:</u>

Johnny Kvernstuen (Group Chief Toxicologist) and **Martin Gjerde Jakobsen** (R&D Senior Chemist Primer Products), Jotun AS, Norway; Provided an overview of Epoxy resin systems (ERS) and the content of sensitizing agents in their products.

Kirsti Krüger (Certified Occupational Hygienist, Equinor); Provided an updated overview of the ERS compounds found in CHESS.

Acknowledgments

Gro Tjalvin (PhD, MD/Senior Consultant Occupational Medicine) was responsible for the project during the application process, **Hilde Vindenes** (MD/senior consultant, Department of Occupational Medicine, HUS) and **Torgeir Storaas**, (PhD, MD/senior consultant, Department of Occupational Medicine, HUS) contributed to the application.

The ISS companies **Beerenberg Solutions, Bilfinger Industrial Services** and **Altrad Linjebygg** contributed with a valuable overview of their most used epoxy paints.

Raymond Olsen (PhD, Research Associate Professor, Chemical Work Environment) at the National Institute of Occupational Health (STAMI), Norway, was consulted in respect to challenges in monitoring ERS-related exposure to sensitizing agents, as well as available analytical services at STAMI.

Roland.chem contributed with front page picture (https://commons.wikimedia.org/w/index.php?curid=23382731)

ISBN 978-82-692241-0-8 (PDF)

SUMMARY

Epoxy resin systems (ERS) are among the major surface coating products used by the surface coating industries in Norway today. The epoxy compounds are known to be potential sensitizers, and may cause occupational allergic contact dermatitis, contact urticaria, and occupational asthma.

Commercially available epoxy coatings mainly consist of an A and a B component. The A component comprises epoxy resin(s), solvents, reactive diluents, and additives including fillers and pigments. In the B component you find the curing agents. Epoxy coating formulations are constantly changing and in this report, we have investigated 61 unique Safety Data sheets (SDS) for components classified with the hazard statement H317 (may cause an allergic skin reaction), H334 (may cause allergy or asthma symptoms or breathing difficulties if inhaled) and H335 (may cause respiratory irritation). Several searches in CHESS showed that the products we examined were representative of today's epoxy products and their components.

Based on reactive groups and structure, the H317 components were organized into 3 groups: epoxy resins, reactive diluents and curing agents. The components were compared with what has been previously described in the literature on epoxy components and epoxy exposure. Many of the components are available in standardized test series and several of them are known to cross-react with each other. Hence, the standardized series cover most components found in today's epoxy products. However, it is important to be aware of other sensitizing agents and perform testing on patients own material or directly on single components obtained from the producers.

Different ERSs consists of different components, making it challenging in relation to exposure measurements. No single agent can be used to monitor exposure, and the sampling strategy must be decided depending on the product recipe. Most of the molecules used in the ERS has a high molecular weight and the exposure will be in the form of an aerosol, and not as a vapor that most of the sampling- and analytical methods are developed for. Hence, the sampling strategy must be decided from case to case depending on the product, application method, as well as the available analysis at the laboratory. The main options for exposure assessment of epoxy resins are still environmental and biological monitoring of amines and the solvent used.

INTRODUCTION

Due to unique technical properties, epoxy resin systems (ERS) are among the major surface coating products used in Norway. ERS comprise compounds that are potential sensitizers, and exposure to ERS is a recognized cause of occupational allergic contact dermatitis, contact urticaria, and occupational asthma.

Due to lack of proper methodology to sample and analyze ERS compounds, information on exposure levels is lacking. Lately, better analytical services for environmental and biological monitoring of ERS-related agents have become available, and the use of these are promising for future exposure assessment of ERS. However, because of the wide variety of components used in ERS, no single agent can be used to monitor exposure, and the sampling strategy must be decided depending on the product recipe. For assessment of allergic contact dermatitis, no single chemical can be used to screen for sensitization, and commercially available patch test series do not cover the full spectrum. Furthermore, new products comprising new chemicals are constantly developed by the ERS-producers, making many of the presently available epoxy patch tests outdated.

In this project, we aim to:

1. Provide an updated overview of the ERS used by Norwegian surface coaters, and their content of sensitizing agents
2. Identify available methods used to assess occupational dermal and inhalable exposure to ERS, and the uptake of relevant ERS compounds
3. Identify the need to supplement epoxy patch test series.

Epoxy resin systems

Epoxy resin systems (ERS) are one of the major surface coating products used in a range of industries both offshore and onshore in Norway, because of their unique technical properties. Commercially available epoxy coatings mainly consist of an A and a B component.

The A component comprises epoxy resin(s) (mainly based on diglycidyl ether of bisphenol A or F), solvents, reactive diluents and additives including fillers and pigments. In the B component you find the curing agents (epoxy resin hardeners).

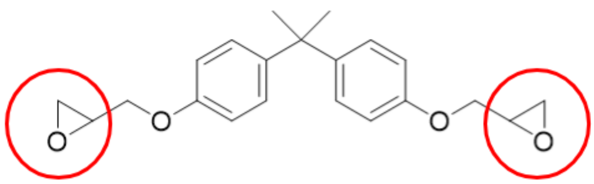

Figure 1. Example of an epoxy resin: DGEBA = **d**iglycidyl **e**ther of **b**isphenol **A**

Epoxy resins contain two or more epoxide functional groups and the resins are dependent on a curing agent in order to form a protective coating film. The epoxy resin and the curing agent polymerize and forms a thermoset polymer. Amines are the most common curing agents and they react generally as many times as it has N-H bonds. The amines are normally made into amine *derivatives* ("modified amines") before being employed as curing agents for epoxy resins.

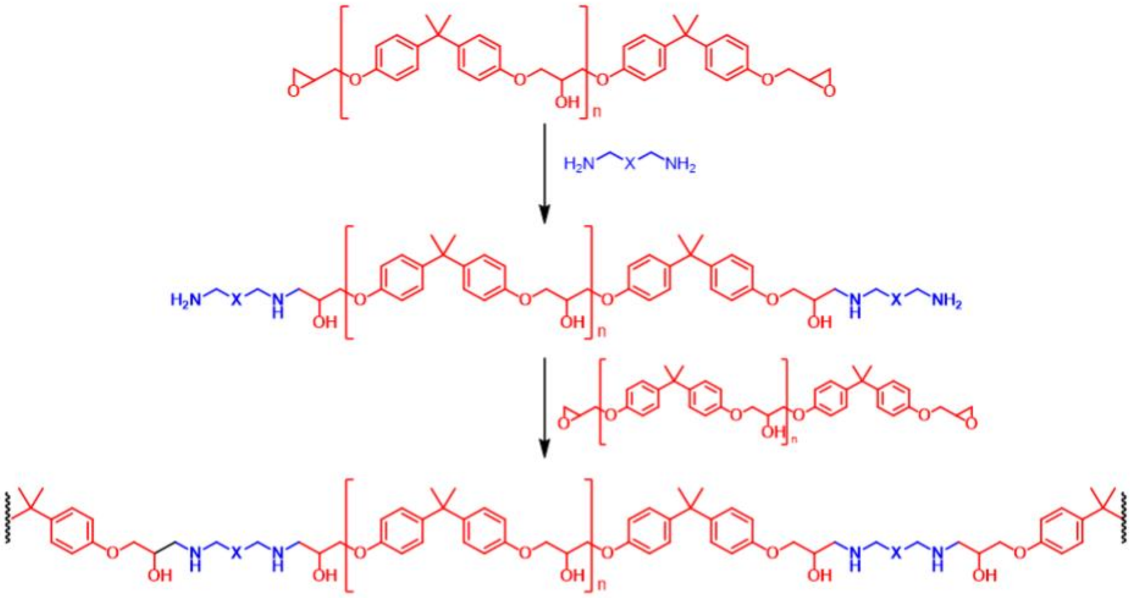

Figure 2. The epoxy resin is marked in red and the simplified structure of the amine curing agent is marked in blue.

The curing reaction starts when the A and B components are mixed. Initially this goes on unnoticed, but eventually an increase in viscosity and generation of heat (exotherm reaction) will be observed. Thus, small molecular reactive species are consumed by additional reactions, and the chance of getting into contact with such substances decreases with time after mixing of the components.

During the curing of epoxy paints, the paint film is formed when the epoxy resin and the amine curing agent forms long polymer chains consisting of alternating epoxy and curing agent molecules. In the end, the formation of a solid strong film also involves cross-linking of such chains by reactions of secondary amines.

The solvents used are mainly xylene, butanol, naphtha and ketones. The reactive diluents are low molecular weight epoxy compounds that are necessary in solvent free systems.

Epoxy coating formulations are constantly changing, and these changes are driven by regulations. In the last 30 years there has been a trend towards less solvents and lower molecular weight epoxy resins. At the same time the need for reactive diluents and lower molecular curing agents has increased. In addition, there has been development of water born systems which introduced the need for additional additives that may be potential sensitizers.

Health hazards of epoxy coatings

Occupational hypersensitivity reactions are among the most common illnesses that affect workers. In this category you find allergic contact dermatitis, contact urticaria and asthma which all may be related to epoxy exposure. Physicians are obligated to notify the authorities, in writing, when acquiring knowledge that an employee may be suffering from work-related illness. Between 2017 and 2019, the Petroleum Safety Authority (PSA) in Norway received 42 reports regarding occupational conditions related to skin and subcutaneous tissue. About 40% of these reports were connected to workers in maintenance, i.e. surface treatment, and 6 out of 42 cases were related to epoxy. In the same period the PSA received 22 reports regarding work-related illness in the respiratory system, none of these were related to epoxy exposure.

Between 2017 and 2019 The Norwegian Labour Inspection Authority received 6 epoxy related reports regarding work-related conditions concerning skin and subcutaneous tissue or the respiratory system. It is important to be aware that there is probably a significant under-reporting of work-related illness to the Norwegian Labor Inspection Authority as only <5% of the doctors send notifications. Thus, the figures do not say anything about the extent of work-related illness among the population, only what has been reported (personal communication).

Occupational exposure to ERS can adversely affect an individual's health and capacity to perform work. Sensitized workers must avoid exposure to the allergen both at work and outside the workplace. This may be achieved by altering workplace tasks and duties, implementing engineering controls, or by providing workers with appropriate personal protective equipment. However, in many cases a sensitized worker will have to move to a completely different area or change to a different workplace or occupation [1].

Contact dermatitis and contact urticaria

Occupational exposure to ERS may cause contact dermatitis, either representing irritant or allergic contact dermatitis.

Irritant contact dermatitis is an inflammatory skin response in which the barrier function is impaired and represents a nonimmunologic mechanism. In general, irritant contact dermatitis accounts for 80 % of all contact dermatitis cases. Examples of ERS with irritant effect are high molecule weight DGEBA epoxy resins, hardeners, epichlorohydrin, glass or carbon fibre-based epoxy composites, reactive diluents or curing agents.

Contact allergy is an immune-mediated reaction in which the individual first undergoes an initial sensitization towards a specific allergen, and then later will present an allergic contact dermatitis (elicitation response). In general, allergic contact dermatitis represents 20 % of cases of contact dermatitis. Several ERS have sensitizing potential, the most important one being DGEBA. However, also other constituents of ERS may act as sensitizers such as hardeners, reactive diluents and other epoxy resins.

Contact urticaria is an immediate IgE-mediated immunologic reaction in which a dermal wheal and flare response occurs in contact with an allergen. Lesions occur after minutes to an hour and resolves within hours. Relatively few cases of contact urticaria has been reported, however both epoxy resins and organic acid anhydride hardeners has been found to cause this condition [2].

Patch testing

Patch testing is the most important diagnostic tool used to diagnose contact allergy. Substances inducing contact allergy are reactive chemicals. These substances become antigenic after binding to proteins and are referred to as haptens. Allergens are applied under occlusion on the skin and under standardized conditions [3].

A chemical is applied in a suitable concentration with solvent (usually petrolatum) in a test chamber, the area and the volume of the chambers are standardized. The test is applied to the back of the patient for 48 hours and then removed. After further 24 hours, on the third day after application and preferably also on the seventh day, readings are made by an experienced dermatologist.

The test substances are available as a series of 20-30 standard chemicals known to induce contact allergy and contact dermatitis [4]. Concentrations and vehicles are carefully selected so as not to result in false positive or false negative test reactions [5]. Information about work environment and exposure is extremely important for the diagnosis of an occupational contact dermatitis [6].

There are different test series from different producers. The European baseline series (S-1000) (Chemotechnique) is an example of a guideline for a minimum set of allergens to which all patients should be tested. It also includes the commonest epoxy allergen, DGEBA. The Epoxy Series (E-1000) from Chemotechnique contains 14 additional epoxy chemicals (from 2020). The European baseline series is dynamic and subject to continual evaluation and occasional modification, depending on population exposures and the prevalence of contact allergy (The most recent update was published in Contact Dermatitis 2019).

Our environment is changing, and workers and consumers are exposed to new chemicals, some of which are allergens. Routine test substances will not identify new allergens. Approximately 4000 contact allergens are known and only 6-700 allergens are available from suppliers [6]. Testing with patients own products is the only way of finding new allergens in the clinic [7]. Previously known allergens can be found in new types of product; that is, testing with patients' own materials may reveal previously unknown sources of sensitization. It is necessary to use the information about the ingredients in the product from the Safety Data Sheet (SDS). Totally unknown products should not be tested.

Occupational asthma

Asthma is a clinical syndrome characterized by reversible airway obstruction, bronchial hyperresponsiveness, and airway inflammation. Epoxy compounds are well known skin sensitizers, but their potential to be respiratory sensitizers is largely unknown. Contact dermatitis is relatively often seen on the face and neck of patients diagnosed with epoxy dermatitis, and even though most of the components in ERS are poorly volatile this is indicative of airborne exposure [8]. Even though early identification of workers at risk for developing respiratory health effects from epoxides has been an area of interest for decades, few systematic studies exist [9]. The term "work related asthma" encompasses both asthmas caused by conditions at work (i.e. occupational asthma) and pre-existing or coincident asthma worsened by non-specific stimuli at work. The agents causing allergic occupational asthma (OA) include both high molecular weight proteins and low molecular weight chemicals. The diagnosis for (OA) asthma is usually made years after onset of symptoms and various tests are used to make a valid diagnosis [10]. As a late diagnosis is associated with poor outcome, there is a need for increased awareness. Workers with suspected OA should have a prompt referral to specialists with expertise and the appropriate equipment.

Specific inhalation challenge

Specific inhalation challenge (SIC) is the gold standard for diagnosing occupational asthma and identifying the causative respiratory-sensitizing agents [11]. Suojalehto and coworkers have recently reported a series of cases of work-related asthma symptoms among workers exposed to ERSs in Finland (99 cases, 2009 to 2018) and Spain (14 cases, 1997 to 2018). In addition to performing SIC, they measured airborne polyamines and organic solvents during a floor coating process. The measured level of solvents was relatively high (range 6 – 278 mg/m3), while the levels of airborne amines was very low, mostly below the limit of detection. A total of 15 out of 113 patients had a positive SIC reaction to ERSs, hence confirming OA. This relatively small amount of positive SICs may indicate that the sensitizing potential for these compounds is low. In addition, two out of the 15 OA positive patients were diagnosed with contact dermatitis from ERS compounds. Considering the low levels of airborne ERS compounds this may support earlier data that suggest that skin exposure may contribute to the development of OA [12].

Department of Occupational Medicine, Haukeland University Hospital, is the only unit in Norway that performs SIC on patients with suspected OA to chemical or biological agents at their workplace. In the period between 2011 and 2020 only 1 out of 150 SICs has been performed by testing epoxy resin product (with non-conclusive result).

Risk assessment and preventive measures

Employers have a duty to identify risk factors related to the work. In addition, the employer is responsible for informing and training the employees in safe handling of work hazards. A risk assessment refers to the identification of hazards and risk factors that has the potential to cause harm. This include factors caused by the work, work facilities and working conditions. The risks shall be analyzed and evaluated, and measures should be implemented to eliminate or reduce the risk to a minimum or an acceptable level. Risk assessments shall be performed prior to start-up and in co-operation with employer and employees, including safety delegates. The occupational health service and a third party, i.e. the client, may also be involved.

The first step in a risk assessment is to identify the risk factors. Regarding chemicals, SDS is the primary source of information. The SDS shall always be up to date and available for the users. Hazards are described with warning symbols and hazard statements (H statements). In assessing the risk for epoxy exposure, it is important to both assess the potential of skin exposure and the potential of respiratory exposure. Some of the components in ERS are often marked H317 “May cause an allergic skin reaction” and some may be marked H334 “May cause allergy or asthma symptoms or breathing difficulties if inhaled”.

The second step is to identify the actual and potential exposure of workers. In this step you need to consider the location, application method, frequency, level, and duration of exposure, need for training and personal protective equipment (PPE). For chemicals like epoxy paints, the application method is of great importance. Spray painting represents a much higher degree of exposure compared to application with brush. This needs to be taken into consideration when assessing the level of risk.

The third step is considering, based on step one and two, how likely it is that the hazard could cause harm. Can you exclude the hazard, or can you control the risk so that harm is unlikely? If you cannot redesign the job or replace materials or processes, you need to organize the work in a way to reduce exposure. This can be by implementing measures like training, job rotation and PPE.

METHOD

Due to covid-19 and travelling restrictions, the collection of data was performed in digital workshops and through e-mail correspondence.

Collection of data

In order to get an overview of the ERSs used today, four of the largest ISS companies operating on the Norwegian continental shelf were contacted. They were asked to come up with top 5-10 epoxy products used by volume. Three of the companies: Beerenberg Solutions, Bilfinger Industrial Services and Altrad Linjebygg replied. The request resulted in more than 50 products. In addition, Jotun provided their top 5 list based on most sold epoxy product. A total of 74 safety datasheets (SDS) were collected. Some of the product overlapped between ISS companies or ISS companies and Jotun. A total of 61 unique SDS were investigated for components classified with the hazard statement H317 (may cause an allergic skin reaction), H334 (may cause allergy or asthma symptoms or breathing difficulties if inhaled) and H335 (may cause respiratory irritation). This resulted in 40 unique H317 classified components, 1 H334 classified component and 11 H335 classified components.

Department of Occupational Medicine at Haukeland University Hospital provided additional 15 H317 classified components related to products used by patients tested for epoxy allergies from 2014 until today. In total we were left with 55 H317 classified components for further investigation.

Table 1. Number of components classified H317, H335 and H334 in the 61 unique SDSs

Classification		No. of components
H317	May cause an allergic skin reaction	55
H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled	1
H335	May cause respiratory irritation	11

Based on reactive groups and structure, the H317 components were organized into 4 groups: epoxy resins, reactive diluents, curing agents and others.
To investigate whether these components were representative of current use, it was investigated whether they were registered in CHESS. CHESS, Chemical, Health, Environment, Safety System is used by Equinor as a database for all chemicals currently in used in the company.

There are some limitations to this project that must be considered:

I. This project is a pilot which was time-limited to 6 months
II. We must assume that the epoxy products presented by the ISS companies are representative of the industry
III. Even though the products we have examined are the most widely used, it might not be that they contain the most allergenic compounds

RESULTS AND DISCUSSION

Overview of H317 components in ERSs

The H317 components were organized into 4 groups: epoxy resins, reactive diluents, curing agents and others. Only the first three groups are reported here. The weight percentage is reported from the SDS from the ISS companies and Jotun but was not included in the information from the Department of Occupational Medicine at Haukeland University Hospital.

The abbreviations for the chemical compounds are not explained in the text, but this information and CAS numbers can be found in the tables.

Epoxy resins

Epoxy resins are among the most important contributors to occupational allergic contact dermatitis. Most of the epoxy resins used today are derived from DGEBA, but resins based on DGEBF are also common. The DGEBF occurs as three different structural isomers, and for two of the isomers there is strong cross-reactivity to DGEBA [13]. The epoxy resins found in this project are derived from DGEBA and DGEBF.
In the Alto-Korte study [8] as many as 82% of the occupational epoxy cases were screened with DGEBA in the baseline series. This is a bit higher than what is reported from Sweden [14], Norway[15] and German speaking countries [16] which report 52-77%. Based on the literature and their own results Alto-Korte et al [8] recommend DGEBF to be tested in addition to DGEBA. Both these resins are tested for by using the European Baseline Series (S-1000) and the Epoxy Series (E-1000) from Chemotechnique.

Table 2. Epoxy resins found in the investigated material

Epoxy resins	Abbreviation	CAS	Weight %
Diglycidyl ether of bisphenol A resin	DGEBA	25068-38-6**	1-75%
Epoxy resin	DGEBA	25085-99-8**	
Poly(bisphenol a-co-epichlorohydrin), glycidyl end-capped	DGEBA	25036-25-3**	≤3-50%
Epoxyharpiks (MW ≤ 700)	DGEBA	1675-54-3**	≤2.3 -≤50%
Diglycidyl ether of bisphenol F resin	DGEBF	28064-14-4*	2,5-25%
Formaldehyd, oligomeric reactionproduct with 1-chloro-2,3- epoxypropane and phenol	DGEBF	9003-36-5	≤5-50%
Phenol, polymer with formaldehyde, glycidyl ether, polymers with [(methylphenoxy) methyl]oxirane and triethylenetetramine		99377-78-3	≥50 - ≤75
4,4'-Isopropylidenedicyclohexanol, oligomeric reaction products with 1-chloro-2,3-epoxypropane	DGEBA	30583-72-3	<1

* Standard test from Chemotechnique
** Standard test from Chemotechnique; a resin, based on epichlorhydrin and bisphenol A

- Although we found many different CAS numbers for the epoxy resins, chemically speaking, it can be said that the CAS numbers for DGEBA listed in table 2 describes the same compound.

It will therefore be sufficient to test for DGEBA and DGEBF to cover all the different epoxy resins we found in our investigated material.

Reactive diluents

Isolated allergic reactions to reactive diluents are rare and usually occurs together with reactions to DGEBA. Diluents with several epoxy groups can be used in some epoxy systems. Thus the distinction between reactive diluents and resins is not always clear [17, 18].

Only 4 different reactive diluents were found among the SDSs investigated and the information from the Department of Occupational Medicine at Haukeland University Hospital. However, these four reactive diluents represent three different groups: aromatic monoglycidyl ethers, aliphatic monoglycidyl ethers and aliphatic diglycidyl ethers. All of these, except CGE, is found in products registered in CHESS. Epoxide 8 and HDDGE being the most common, found in 86 and 39 products, respectively. CGE was only found in one product related to a patient assessment back in 1999. According to recent information from industry (May 2020), CGE is rarely used and this in accordance with the information given by Geier et al. in the EPOX 2002 study. HDDGE is found in the Epoxy series (E-1000) from Chemotechnique. Both HDDGE and Glycidyl ether of 3-alkyl phenol, like many other glycidyl derivates, are known to cross-react with DGEBA. Epoxide 8 is the most common reactive diluent both in our material and in the Finnish Product Register of Chemicals. However, its clinical significance is unclear, and it has been suggested testing Epoxide 8 in parallel with other aliphatic glycidyl ethers to confirm or rule out cross-reactions and sensitizing potential [17].

Table 3. Reactive diluents found in the investigated material

Reactive diluents	**Abbreviation**	**CAS**	**Weight %**
1,6-hexanediol glycidyl ether	HDDGE	16096-31-4*	2,5-10%
Glycidyl ether of 3-alkyl phenol		68413-24-1	≤5 -≤75%
Alkyl (C12-14) glycidyl ether	Epoxide 8	68609-97-2	<1-25%
Cresyl glycidyl ether	CGE	26447-14-3	

* Standard test from Chemotechnique

- We found only four different reactive diluents. This has to do with the fact that there is little need to use reactive diluents in solvent-based products. All identified reactive diluents are glycidyl derivates, and like other glycidyl derivates they are known to cross-react with DGEBA.

Curing agents

There are a variety of curing agents and which one is used depends on the requirement of the products and the conditions of use. As for reactive diluents, there is only a minority of patients that develops isolated contact allergy to epoxy curing agents [7, 18].

Aa shown in table 4 we found 21 different curing agents in the investigated material. By searching in CHESS, we found that these components were registered 597 times. The most common were Tris-DMP, MXDA (both aromatic) and IPDA (aliphatic) with 100, 99 and 90 registrations respectively. These are the same curing agents identified as the most common in inducing allergic reactions in former studies [7, 15, 16]. The next in line were TETA and DETA with 52 and 39 times respectively. All these well-known curing agents are found in the Epoxy series (E-1000) from Chemotechnique.

In addition to the well-known curing agents, we also identified FBAP to be part of the investigated material. This curing agent was found both in the material related to patient assessment and in SDS from the ISS companies. However, it was linked to a single product which is designed particularly as a primer for flooring systems for offshore and ship installations. This component was registered 33 times in CHESS. A patch test substance for FBAP is not commercially available, but 2 cases of occupational contact dermatitis caused by FBAP has recently been reported by Suomela and colleagues [19].

Table 4. Curing agents found in the investigated material

Curing agents	Abbreviation	CAS	Weight %
1-[3-(aminomethyl)phenyl]methanamine	MXDA	1477-55-0*	2,5-50%
2, 4, 6-tris(dimethylaminomethyl)phenol	Tris-DMP	90-72-2*	0,1-10%
3-aminomethyl-3,5,5-trimethylcyclohexylamine	IPDA	2855-13-2*	1,0- ≤25%
Triethylenetetramine	TETA	112-24-3*	0,1-10%
3-(dimetylamino)propylamine	DMPA	109-55-7*	0,1-1,0%
Aminepoxyadduct		1075254-00-0	≤10 - ≤75
triethylenetetramine fraction		90640-67-8	0,1-75%
1,2-syklohexandiamine		694-83-7	1-2,5%
Ethylendiamine; 1,2-diaminoetan	EDA	107-15-3	≤0,3
2,2,4(or 2,4,4)-trimethylhexane-1, 6-diamine	TMD	25513-64-8	≤7.3
Bis(2-aminoethyl)amine	DETA	111-40-0*	≤0.76
Formaldehyde, polymer with benzenamine	FBAP	135108-88-2	25-50%
Tetraethylenepentamine	TEPA	112-57-2	≤3
Cyclohexanamine, 4,4'- methylenebis		1761-71-3	≤3
Trimetylhexametylendiamine	TMD	25620-58-0	
4-[(4-amino-3-methylcyclohexyl)methyl]-2-methylcyclohexan-1-amine		6864-37-5	
3,3'-[oxybis(ethane-2,1-diyloxy)]dipropan-1-amine		4246-51-9	
2-(2-Aminoethylamino)ethanol		111-41-1	
Fatty acids, C18-unsatd., dimers, polymers with 3,3'-[oxybis(2,1-ethanediyloxy)]bis[1-propanamine]		68911-25-1	
Tetraethylenepentamine fraction		90640-66-7	

* Standard test from Chemotechnique

- We found 21 different curing agents in the investigated material, where six of them are found in the commercial test series from Chemotechnique.
- The five most common curing agents in our investigated material, all found in the commercial test series, were registered almost 400 times in CHESS. Our findings correlate well with what has been previously described in the literature about common curing agents.
- In addition to the well-known curing agents we found FBAP in the investigated material. This agent has recently been associated with contact dermatitis

Overview of H334 and H335 components in ERSs

Only one H334 (may cause allergy or asthma symptoms or breathing difficulties if inhaled) component were identified, Ethylenediamine (CAS no. 107-15-3). Ethylenediamine (EDA) also has the hazard statement H317 (may cause an allergic skin reaction). EDA is a chemical of low molecular weight. Many amines have been described as potential causative agents for OA, and ethylenediamine is one of the most implicated of this condition. Dernehl [20] provided the first description of OA due to ethylenediamine among workers in the epoxy resin industry and Gelfand [21] implicated this agent by using SIC back in 1963 [22]. The mechanism behind is not well defined, but studies suggest it to be an immunological mechanism where the amine acts as a hapten to provoke an immunological response [23, 24].

There are several reports that exposure to ERS may cause OA [12, 25-32]. Sensitizing agents known to cause dermal and airway diseases are mainly studied in separate organ systems. There are a few case-reports on ERS-induced allergies describes concomitant dermal and airway diseases, but the question remains whether exposure through skin or by inhalation can induce sensitization and immunological responses in another organ [12, 26, 27, 30, 33].

To investigate the content of respiratory irritating agents, we decided to look for compound with the H335 classification (may cause respiratory irritation). Here we found both organic solvents, acrylates and amines. Acrylates are known sensitizers; although seldom being found in surface coating products, they may have other areas of use (e.g. in glue) which are also relevant for the industry. Thus, when performing patch tests, all relevant sensitizers should be considered.

A better indicator for respiratory irritation (if the substance is accessible to the airways) may be the CLP classification Skin Corr 1 and hazard statement H314 (causes sever skin burns and eye damage) as many curing agents are indeed irritating in the airways due to their corrosiveness/high pH.

Table 5. Overview of H334 and H335 components found in the investigated material

H335 Components		**CAS**	**Weight %**
2-metylpropan-1-ol		78-83-1	2,5-10%
Mica potassium aluminum silicate		12001-26-2	10-25%
Xylene		1330-20-7	1,0-50%
4-methylpentan-2-one		108-10-1	1.0-25%
Butan-1-ol		71-36-3	2,5-25%
Butyl acrylate		141-32-2*	0.1-1.0%
Methyl methacrylate		80-62-6*	0.1-1.0%
hydrocarbons, C9, aromatics		64742-95-6	≤3%
Bis(2-aminoethyl)amine	DETA	111-40-0*	≤0.76%
2-methylpentane-1,5-diamine		15520-10-2	≤5%
2-methoxypropanol		1589-47-5	<0.3%
H 334 Component			
Ethylenediamine; 1,2-diaminoethan	EDA	107-15-3	≤0.3 - <1%

* Standard test from Chemotechnique

- We only found one component, ethylenediamine, with the H334 hazard statement. Ethyleneamine is well known for being a potential agent for OA.
- The H335 classified components found are not specific for ERS and therefore not further discussed.

Exposure assessment of epoxy resin systems – available methods

Methods of application. According to the Product data sheets for the 61 identified products, the main method of application is by spray painting, while brush or roll is used at smaller surface areas. Spray painting of ERS will result in an aerosol comprising a mixture of reactive uncured and polymerized (cured) epoxy resin and hardeners. In addition, there is a potential for exposure during mixing of component A and B, as well as cleaning of equipment after spray-painting and painting with brush/roll. Except from two studies reporting low levels of amines in the work atmosphere among surface workers applying ERS-products [12, 34], information on exposure that can be used in the risk assessment for these exposure scenarios in in the surface coating industry are lacking.

Main routes of exposure. The main route of exposure of the ERS-related compounds will depend on the task (e.g. mixing, spray painting, cleaning) and whether the amines are in the vapour or solid/liquid phase. For volatile amines, the most important route of exposure is the inhalatory route, and a recent study indicates a limited capacity for amine with a high volatility to be absorbed through the skin [35]. However, amines have been found to be absorbed through skin [36], and the potential for dermal contact and absorption will increase with decreasing volatility. Diet and oral intake is the main source for human bisphenol exposure, but it has been reported that bisphenols [37-39] can penetrate the skin and become bioavailable. Finally, although uptake of xylene and other solvents can occur across the dermal route, these compounds are mainly absorbed by the inhalatory route.

Hence, although inhalation is the most likely route of exposure during spray painting, dermal contact with ERS through vapor, aerosols or liquid splash, or through the contact with contaminated surfaces and equipment, might contribute to the exposure burden of the ERS-compounds.

Environmental and biological monitoring

In later years better analytical services for environmental and biological monitoring of bisphenol A and F, as well as several amines, have become available. However, there are still many challenges in respect to choosing an optimal sampling strategy for surface coating using ERS-products. Firstly, due to the wide variety of components used in ERS, no single agent can be used alone to monitor exposure to the products. Secondly, most of the molecules used in the ERS has a high molecular weight. Hence, the exposure will be in the form of an aerosol, and not as a vapor that most of the sampling- and analytical methods are developed for. Hence, the sampling strategy must be decided from case to case depending on the product, application method, as well as the available analysis at the laboratory.

We have organized the compounds identified in the ERS products selected in this project into 4 groups: epoxy resins, curing agents, reactive diluents, and others (incl. solvents). Available routine analytical services for the assessment of ERS-exposure provided by STAMI and HSL in UK are given in table 6 below.

Resins. In the ERS-mixture used, bisphenol A **(**BPA)/bisphenol F (BPF) and the diglycidylether are in the form of DGEBA/DGEBF monomer or oligomers. Most analytical services are developed for free BPA/F (free) in air and urine, and not for the reaction product with glycidyl ether. Hence, due to very low residual BPA/BPF in the ERS-mixture this is not a recommended method for monitoring of the epoxy resins.

STAMI is in the process of establishing a method for determination of BPA and BPF in urine with a limit of quantification that is sufficient for detecting the level that is relevant in industries with exposure to products comprising at least some uncured BPA/BPF. At HSL UK it is not offered as a routine analysis, but it is possible if asked for.

Curing agents (epoxy resin hardeners). A challenge when assessing the level of amines in the work atmosphere during use of ERS-products with amine hardeners, is that the available analytical methods is based on determination of vaporous amines. The suitability will hence depend on the volatility of the amine (i.e. whether it evaporates from the ERS-mixture/paint). Further, when the exposure is in the form of an aerosol, which is the case for spray painting of epoxy-products, the methods (adsorbent or filter) will underestimate the exposure level since amines from the droplets of paint will cure on the filter before they get the chance to react with the reagent on the adsorbent or filter. Both STAMI and HSL UK offer analysis of amines.

Reactive diluents. No routine analytical service is available for reactive diluents given for the reviewed products.

Solvents. Determination of the solvents used in the epoxy-products has been the main strategy used when assessing the exposure for surface workers handling epoxy products. This sampling strategy is feasible when using it for exposure reduction purposes, but it is a rather poor proxy for the sensitizing agents found in these products. Also, due to regulations there is a shift towards ERS-products without solvents, making this method less useful in the future.

In conclusion, based on the scientific literature, as well as available analytical services from laboratories, the main options for exposure assessments of epoxy resins are still amines and the solvent xylene (and ethylbenzene).

Assessment of skin exposure

The main effect after exposure to ERS in the surface coating industry is allergic contact dermatitis. Further, some of the ERS-related compounds can also cause systemic effects and dermal uptake of these might potentially contribute significantly to the total internal dose. Hence, a sampling strategy that includes assessment of skin exposure that can identify possible sources of exposure in a workplace, the likely routes of exposure, as well as the magnitude of exposure, is imperative.

At present there are no standardized method for quantifying dermal exposure and uptake, and no dermal occupational exposure limits exist. This also applies to exposure to ERS-products. However, for dermal exposure assessment methods in general there are several approaches available, including semiquantitative methods such as DREAM **(D**e**r**mal **E**xposure **A**ssessment **M**ethod) [40] and EASE (**E**stimation and **A**ssessment of **S**ubstance **E**xposure) [41, 42], use of fluorescence techniques [43], and patch sampling or wiping the skin and surfaces [44].

For workers handling ERS during relining of fold sewage pipes, interviews, observations and skin exposure measurements by patch and surface sampling (tape-stripping method) helped identifying tasks and surface contaminations that contributed to skin exposure of epoxy resin [45, 46]. The tape-stripping method involves applying a strip of adhesive tape to an area of skin (e.g. index finger, thumb, palm, wrist or face) following exposure, leave it on the skin for a specific amount of time, then removing the tape along with the contaminant and some micrometers of the outermost layer of skin. The contaminant is then extracted and analyzed [44].

Several factors will affect variability in the measured exposure [44], including the time-dependent concentration of the contaminant on the skin, compound-specific factors (e.g. polarity, chemical structure, volatility), skin-specific factors (the condition of the skin, skin temperature, skin thickness, skin perfusion, and lipid-protein makeup), the presence of absorption enhancing concomitant exposures, and occlusion and contamination due to inappropriate use of gloves or work suits.

Table 6 An overview over ERS-relevant routine analytical services available from STAMI and HSL UK.

Analythical laboratory		**Bisphenol A/F**		**Amines**			**Solvents**	
		Air	**Urin**	**Air**		**Urin**	**Air**	**Urin**
STAMI	Analytes	Bisphenol; A (CAS 80-05-7) Bisphenol F (CAS 620-92-8) Bisphenol A diglycidyl ether (DGEBA, CAS 1675-54-3) - **not available**	*BPA/F	Primary and secondary amines in vapour phase	Tertiary amines in vapour phase (Triethylamine and trimethylamine)	NA	Xylene and ethylbenzene	**Metabolites of: Xylene (methylhippuric acid) Ethylbenzene (mandelic acid)
	Sampling and analytical method	PVC or PTFE filters in Millipore filtercasette	UHPLC-MS	XAD-2 sorbent tubes impregnated with 1-naftylisotiocyanat HPLC-UV	**XAD-7 sorbent** GC-FID (OSHA PV2060)	NA	Active sampling: sorbent tubes Passive sampling: dosimeters GC-FID (NIOSH 1500 + NIOSH 1501)	UHPLC-MS
HSL (UK)	Analytes	Bisphenol; A (CAS 80-05-7) Bisphenol F (CAS 620-92-8) Bisphenol A diglycidyl ether (DGEBA, CAS 1675-54-3)	BPA/F Possible but not a standard method	Epoxy resin hardeners Meta-xylenediamine (m-XDA, CAS 1477-55-0) Diethylenetriamine (DETA, CAS 111-40-0) 2,4,6-Tris(dimethylaminomethyl)phenol (TDP, CAS 90-72-2) 4,4'-diaminodicyclohexylmethane (DADHM, CAS 1761-71-3)		m-XDA, DDHM, IPDA Others on list that may be possible (untested): • TETA • DMPA • Cyclohexanediamine • 4,4′-Methylenebis(cyclohexylamine)	Xylene and ethylbenzene VOCs listed MDHS 104 BTEX Alcohols, ketones, acrylates and ethers. AGE alkyl (C13) glycidyl ether	Metabolites of: • Xylene (methylhippuric acid) • Ethylbenzene (mandelic acid) Headpsace analysis: • 4-metylpentan-2-one (MIBK) Others on list that may be possible (untested/no interpretation): Headpsace analysis:

				Trimethylhexamethyldiamine (TMD, CAS 25620-58-0)			• 2-Methyl-1-propanol • Butan-1-ol
	Sampling and analytical method	OSHA 1018 GFA filter HPLC UV	LC-MS/MS	m-XDA, DETA and DADHM and TMD: Acid coated filter NIT derivatisation HPLC UV. TDP: PTFE filter BSTFA derivatisation GCMS	GC-MS	Sorbent tubes (recommended sampling media: ATD Tube) Thermal desorption using ATD-GC-FID/ATD-GC-MS (MDHS 104) AGE charcoal tube solvent desorption GCMS	HPLC-UV Headspace-GC-MS

* The analytical method for BPA/F is under development, ** The analytical method for xylene- and ethylbenzene metabolites is under development. GC-FID = Gas Chromatography Flame Ionization Detector, HPLC-UV = High Performance Liquid Chromatography, UHPLC-MS = Ultra High Performance Liquid Chromatography

CONCLUSION

This project had three main aims:

1. **Get an updated overview of the ERS used by Norwegian surface coaters, and their content of sensitizing agents.**
   This aim has been achieved based on:

- Safety data sheets from a representative range of presently used epoxy products (61 unique SDS) and patient assessment material have been analyzed for components classified with the hazard statement H317 (may cause an allergic skin reaction, 55 components), H334 (may cause allergy or asthma symptoms or breathing difficulties if inhaled, 1 component) and H335 (may cause respiratory irritation 11 components).
- Components related to epoxy-specific sensibilization were divided into three groups; resins, curing agents and reactive diluents and compared with previous findings in the literature. The group of curing agents was the largest group consisting of 21 compounds.

2. **Identify available methods used to assess occupational dermal and inhalable exposure to ERS, and the uptake of relevant ERS compounds.**
   This aim has been achieved based on:

- The sampling strategy must be decided from case to case depending on the product, application method, as well as the available analysis at the laboratory. However, the main options for exposure assessment of epoxy resins are still environmental and biological monitoring of amines and the solvent used.
- There are no routine analytical methods available for the reactive diluents identified in this project
- Other than biomonitoring of the internal dose of the ERS-related amines or solvents, there are no standardized method for quantifying dermal exposure and uptake, and no dermal occupational exposure limits exist.

3. **Identify the need to supplement epoxy patch test series.**
   This aim has been achieved based on:

- Results from the review of the Safety data sheets and the systematization of the components shows that current test series, European baseline series (S-1000) and Epoxy series (E-1000), Chemotechnique, cover most components found in today's epoxy products.
- However, it is important to be aware of other sensitizing agents and perform testing on patients own material or directly on single components obtained from the producers. This requires dedicated personnel and time and must only be done in clinical units with sufficient resources.

REFERENCES

1. Anderson, S.E., C. Long, and G.S. Dotson, *Occupational Allergy.* Eur Med J (Chelmsf), 2017. **2**(2): p. 65-71.
2. Claire Higgins, J.C., Riita Jolanki, and and R. Nixon, *Epoxy Resins*, in *Kanerva's Occupational Dermatology*, S.M.J.e. al., Editor. 2020, Springer Nature Switzerland AG.
3. Lachapelle, J.-M., Maibach, Howard I, *Patch Testing and Prick Testing*. 2020: Springer.
4. Johansen, J.D., et al., *European Society of Contact Dermatitis guideline for diagnostic patch testing - recommendations on best practice.* Contact Dermatitis, 2015. **73**(4): p. 195-221.
5. Groot, A.C.d., *Patch Test Concentrations and Vehicles for Testing Contact Allergens*, in *Kanerva's Occupational Dermatology*, J.J. John S., Rustemeyer T., Elsner P., Maibach H., Editor. 2020, Springer, Cham: Springer Nature Switzerland AG 2020.
6. Krautheim A., L.H., Geier J. , *Patch Testing with Patient's Own Materials Handled at Work.*, in *Kanerva's Occupational Dermatology*, J.J. John S., Rustemeyer T., Elsner P., Maibach H., Editor. 2020, Springer.
7. Aalto-Korte, K., et al., *Contact allergy to epoxy hardeners.* Contact Dermatitis, 2014. **71**(3): p. 145-53.
8. Aalto-Korte, K., M. Pesonen, and K. Suuronen, *Occupational allergic contact dermatitis caused by epoxy chemicals: occupations, sensitizing products, and diagnosis.* Contact Dermatitis, 2015. **73**(6): p. 336-42.
9. Hines, S.E., et al., *Cross-Sectional Study of Respiratory Symptoms, Spirometry, and Immunologic Sensitivity in Epoxy Resin Workers.* Clin Transl Sci, 2015. **8**(6): p. 722-8.
10. Vandenplas, O., H. Suojalehto, and P. Cullinan, *Diagnosing occupational asthma.* Clin Exp Allergy, 2017. **47**(1): p. 6-18.
11. Vandenplas, O., et al., *Specific inhalation challenge in the diagnosis of occupational asthma: consensus statement.* Eur Respir J, 2014. **43**(6): p. 1573-87.
12. Suojalehto, H., et al., *Occupational Asthma From Epoxy Compounds.* J Allergy Clin Immunol Pract, 2019. **7**(1): p. 191-198.
13. Ponten, A., et al., *Sensitizing capacity and cross-reaction pattern of the isomers of diglycidyl ether of bisphenol F in the guinea pig.* Contact Dermatitis, 2002. **47**(5): p. 293-8.
14. Ponten, A., et al., *Epoxy-based production of wind turbine rotor blades: occupational contact allergies.* Dermatitis, 2004. **15**(1): p. 33-40.
15. Romyhr, O., et al., *Allergic contact dermatitis caused by epoxy resin systems in industrial painters.* Contact Dermatitis, 2006. **55**(3): p. 167-72.
16. Geier, J., et al., *An attempt to improve diagnostics of contact allergy due to epoxy resin systems. First results of the multicentre study EPOX 2002.* Contact Dermatitis, 2004. **51**(5-6): p. 263-72.
17. Aalto-Korte, K., et al., *Contact allergy to reactive diluents and related aliphatic epoxy resins.* Contact Dermatitis, 2015. **72**(6): p. 387-97.
18. Jolanki, R., T. Estlander, and L. Kanerva, *182 patients with occupational allergic epoxy contact dermatitis over 22 years.* Contact Dermatitis, 2001. **44**(2): p. 121-3.
19. Suomela, S., et al., *Occupational contact dermatitis caused by hydrogenated formaldehyde-benzenamine polymer (FBAP) in epoxy hardeners.* Contact Dermatitis, 2017. **77**(5): p. 341-343.
20. Dernehl, C.U., *Clinical experiences with exposures to ethylene amines.* Industrial medicine & surgery, 1951. **20 12**: p. 541-6.
21. Gelfand, H.H., *Respiratory Allergy Due to Chemical Compounds Encountered in the Rubber, Lacquer, Shellac, and Beauty Culture Industries.* J Allergy, 1963. **34**: p. 374-81.
22. Villar-Gomez, A., et al., *Occupational asthma caused by inhalation of surfactant composed of amines.* Scand J Work Environ Health, 2009. **35**(6): p. 475-8.
23. Casas, X., et al., *[Occupational asthma due to amines].* Arch Bronconeumol, 2002. **38**(2): p. 93-4.
24. David I. Bernstein, M.C.-Y., Jean-Luc Malo, I. Leonard Bernstein, *Asthma in the Workplace*. 3 ed. 2006: CRC Press.
25. Nakazawa, T. and S. Matsui, *Ethylenediamine-induced late asthmatic responses.* J Asthma, 1990. **27**(4): p. 207-12.

26. Moulin, P., A. Magnan, and M.P. Lehucher-Michel, *Occupational allergic contact dermatitis and asthma due to a single low molecular weight agent.* J Occup Health, 2009. **51**(1): p. 91-6.
27. Kanerva, L., et al., *Occupational allergic airbone contact dermatitis and delayed bronchial asthma from epoxy resin revealed by bronchial provocation test.* Eur J Dermatol, 2000. **10**(6): p. 475-7.
28. Arrandale, V.H., et al., *Occupational contact allergens: are they also associated with occupational asthma?* Am J Ind Med, 2012. **55**(4): p. 353-60.
29. Authried, G., et al., *[Delayed asthma bronchiale due to epoxy resin].* Ugeskr Laeger, 2013. **175**(44): p. 2643-4.
30. Hannu, T., et al., *IgE-mediated occupational asthma from epoxy resin.* Int Arch Allergy Immunol, 2009. **148**(1): p. 41-4.
31. Lillienberg, L., et al., *Occupational exposure and new-onset asthma in a population-based study in Northern Europe (RHINE).* Ann Occup Hyg, 2013. **57**(4): p. 482-92.
32. Brock Jacobsen, I., et al., *Delayed occupational asthma from epoxy exposure.* Occup Med (Lond), 2019. **69**(7): p. 511-514.
33. Kanerva, L., et al., *Immediate and delayed allergy from epoxy resins based on diglycidyl ether of bisphenol A.* Scand J Work Environ Health, 1991. **17**(3): p. 208-15.
34. Olve Rømyhr 1, M.B., Marianne Dalene 3, Daniel Karlson 3, Roger Lindahl 4, Gunnar Skarping 3, Hans Thore Smedbold 1, Håkon Lasse Leira, *Yrkeshygieniske målinger ved påføring av epoksy- og polyuretanbaserte industrimalinger*. 2002, Arbeidsmedisinsk avdeling,St. Olavs hospital HFUniversitetssykehuset i Trondheim: Trondheim, Norway.
35. Thredgold, L., et al., *Skin Notations for Low-Molecular-Weight Amines: Development of a Testing Protocol with Isopropylamine as an Example.* Ann Work Expo Health, 2018. **62**(5): p. 633-638.
36. Hotchkiss, S.A., P. Hewitt, and J. Caldwell, *Percutaneous absorption of 4,4'-methylene-bis(2-chloroaniline) and 4,4'-methylenedianiline through rat and human skin in vitro.* Toxicol In Vitro, 1993. **7**(2): p. 141-8.
37. Demierre, A.L., et al., *Dermal penetration of bisphenol A in human skin contributes marginally to total exposure.* Toxicol Lett, 2012. **213**(3): p. 305-8.
38. Mielke, H., F. Partosch, and U. Gundert-Remy, *The contribution of dermal exposure to the internal exposure of bisphenol A in man.* Toxicol Lett, 2011. **204**(2-3): p. 190-8.
39. Lu, S., et al., *Estimation of intake and uptake of bisphenols and triclosan from personal care products by dermal contact.* Sci Total Environ, 2018. **621**: p. 1389-1396.
40. Van-Wendel-de-Joode, B., et al., *DREAM: a method for semi-quantitative dermal exposure assessment.* Ann Occup Hyg, 2003. **47**(1): p. 71-87.
41. Tickner, J., et al., *The development of the EASE model.* Ann Occup Hyg, 2005. **49**(2): p. 103-10.
42. Creely, K.S., et al., *Evaluation and further development of EASE model 2.0.* Ann Occup Hyg, 2005. **49**(2): p. 135-45.
43. Cherrie, J.W., et al., *Use of qualitative and quantitative fluorescence techniques to assess dermal exposure.* Ann Occup Hyg, 2000. **44**(7): p. 519-22.
44. Vermeulen, R., P. Stewart, and H. Kromhout, *Dermal exposure assessment in occupational epidemiologic research.* Scand J Work Environ Health, 2002. **28**(6): p. 371-85.
45. Suuronen, K., et al., *Skin exposure to epoxy chemicals in construction coating, assessed by observation, interviews, and measurements.* Contact Dermatitis, 2019. **80**(1): p. 18-25.
46. Henriks-Eckerman, M.L., et al., *Role of dermal exposure in systemic intake of methylenediphenyl diisocyanate (MDI) among construction and boat building workers.* Toxicol Lett, 2015. **232**(3): p. 595-600.