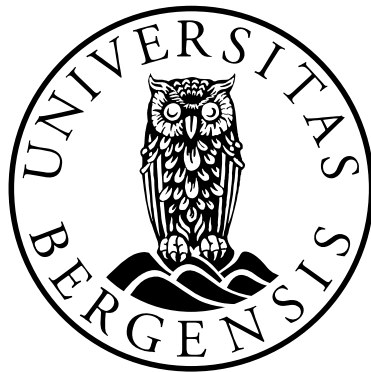


# **Respiratory Health among Cement Workers in Ethiopia**

**Zeyede Kebede Zeleke**



Dissertation for the degree philosophiae doctor (PhD)  
at the University of Bergen

2011



## Acknowledgements

First and foremost I am grateful to the almighty God for giving me strength and energy to accomplish my doctoral training.

I am sincerely grateful to the Government of Norway for funding my scholarship. The Norwegian State Educational Loan Fund (Lånekassen) and the Norwegian State Education Fund (NUFU) facilitated the project taking place successfully.

I will forever be indebted to my supervisors, Professor Bente Elisabeth Moen and Professor Magne Bråtveit; I am shorts of appropriate words of appreciation. I really thank you in a very special way for your tireless effort in giving me valuable guiding advice throughout the training period. Your challenging guidance and criticism made me what I am today.

I wish to express my deepest and sincere appreciation to all administrative staff both at the Center for International Health (CIH) and Department of Public Health and Primary Health Care (ISF) for their assistance with all kinds of practicalities during my research work. Borgny, Unni, Solfrid and Ana Veronica Cordova, Thank you very much.

I express my sincere gratitude to my colleagues at Occupational and Environmental Medicine for their friendly and supportive environment they created for my entire period of study. I want to give special thanks to Berit Larsen, Valborg Baste, Nils Magerøy, Hilde Gundersen, Kristn Bondevik, Ole Jacob Møllerløyken, Kjersti Alsaker, Inger Haukenes, Jorunn Kirkeleit, Alexander Tungu and Gloria Sakwari. Every one of you had great contribution by sharing your ideas during peer group sessions.

To my Fiancé Bezawit, I can never have enough words to thank you for your love, encouragement and endurance of my long absence.

To my sisters, Zinaye, Armaye and Tigist and to my brothers Firew, Taweke, Miruk and Tadesse, I thank you very much for your love and support.

I will always cherish memories of my friends in Bergen; Tadesse Negash, Abduljelil Sultan, Henok Mekonnen, Sileshi Gizachew, Kifle Assefa, Elias Alemu , Dr. Thomas Bogale and Alemnesh Mirkuze. I deeply appreciate the cooperation, friendship and support.

Special thanks to my friends, Ebba Abate, Amare Workiye, Endris Mekonnen, Gulilat Amde, Lule Teshager, Dr Zelalem Tadesse, Dr Amaha Abebe, Getachew Hailemariam and Tewodros Husen. You are really brothers to me. Thank you all for your wonderful support.

I would like to thank the managements of Dire Dawa cement factory, Mughher Cement Enterprise and Messebo cement factory for accepting and facilitating the smooth running of the project.

Last but most importantly, I am grateful to all study participants who agreed to participate in this study. Without them, this work would not be possible. Thank you!

## Abstract

**Background:** Little is known on dust exposure and respiratory health among cement cleaners. There are only a few follow-up studies on respiratory health among cement factory workers and also studies on acute effects of cement dust exposure are limited in numbers.

**Objective:** This study aimed at assessing cement dust exposure and adverse respiratory health effects among Ethiopian cement production workers, with particular focus on cement cleaners.

**Method:** The first paper was a combined cross-sectional and cross-shift study. Forty exposed cement production workers from the crusher and packing sections and 20 controls from the guards were included. Full-shift personal total dust was measured in the breathing zone of the workers and Peak expiratory flow (PEF) was measured for all selected workers before and after the shift. A modified respiratory symptom score questionnaire was used to assess acute respiratory symptoms experienced at the end of the work shift.

The second paper comprises an exposure assessment carried out in two cement factories (A and B). Personal full-shift samples of total (n=150) and respirable dust (n=36) were taken in the breathing zone of 105 cement workers.

The third paper was a follow-up study, 112 personal total dust samples were collected from 46 workers. In total 127 workers; 56 cleaners, 44 cement production workers and 27 controls were randomly selected and examined for lung function and interviewed about chronic respiratory symptoms at baseline in 2009. Of these, 91 workers; 38 cement cleaners, 33 cement production workers and 20 controls were re-examined with the same methods one year later.

## Results

In the first paper we found that the exposed workers had considerably higher geometric mean (GM) total dust exposure ( $38.6 \text{ mg/m}^3$  and  $18.5 \text{ mg/m}^3$  in the crusher and packing, respectively) than the controls ( $0.4 \text{ mg/m}^3$ ). Stuffy nose (85 %), shortness of breath (47 %) and sneezing (45 %) were the most prevalent acute respiratory symptoms among the high exposed workers. PEF decreased significantly across the shift in the high exposed group.

In the second paper, cleaners had significantly higher exposure to total and respirable dust than other production workers. Among cleaners, the GM for total and respirable dust exposure were 549 and  $6.8 \text{ mg/m}^3$  in Factory A and 153 and  $2.8 \text{ mg/m}^3$  in Factory B. Temporal variability (within-worker) dominated the variability in the cleaners' total dust exposure. The distance from machines while performing cleaning tasks and the fraction of working hours spent on cleaning explained about 73 % of the temporal variability in total dust exposure among cleaners. Only 7 % of the cement production workers used respiratory protective devices.

In the follow-up study, total GM dust exposure among cleaners was  $432 \text{ mg/m}^3$ . The levels were considerably lower among the production workers ( $\text{GM}=8.2 \text{ mg/m}^3$ ), but still 48% exceeded  $10 \text{ mg/m}^3$ . The prevalence of all the chronic respiratory symptoms among both cleaners and production workers was significantly higher than among the controls. Forced Expiratory Volume in one second ( $\text{FEV}_1$ ) and  $\text{FEV}_1/\text{Forced Vital Capacity}$  ( $\text{FEV}_1/\text{FVC}$ ) were significantly reduced from 2009 to 2010 among the cleaners and production workers, but not among the controls.

## Conclusion

This study has shown increased prevalence of acute and chronic respiratory symptoms as well as reduced lung function among dust exposed cement production workers and excessively exposed cleaners than among the less exposed controls. It is likely that the adverse respiratory health effects are related to the dust exposure.



## List of publications

The thesis is based on the following papers

- I. Zeleke Z, Moen BE, Bråtveit M. Cement dust exposure and acute lung function: A cross shift study. *BMC Pulmonary Medicine* 2010, 10:19.
- II. Zeleke Z, Moen BE, Bråtveit M. Excessive exposure to dust among cleaners in the Ethiopian cement industry. *J Occup Environ Hyg*, in press.
- III. Zeleke Z, Moen BE, Bråtveit M. Lung function reduction and chronic respiratory symptoms among workers in the cement industry: A Follow up study. Submitted



## Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
AM	Arithmetic mean
ANOVA	Analysis of Variance
ATS	American Thoracic Society
BMRC	British Medical Research Council
FEF <sub>50</sub>	Forced Expiratory Flow at 50% of FVC
FEF <sub>75</sub>	Forced Expiratory Flow at 75% of FVC
FEF <sub>25-75%</sub>	Forced Expiratory Flow at the middle part of FVC maneuver
FEV <sub>1</sub>	Forced Expiratory Volume in first second
FEV <sub>1</sub> /FVC	The ratio of Forced Expiratory Volume in first second to Forced Vital Capacity
FVC	Forced Vital Capacity
GM	Geometric Mean
GSD	Geometric Standard Deviation
IOM	Institute of Occupational Medicine
ISO/CEN	International Organization for Standardization/Comite Europeen de Normalisation
MCE	Mugher Cement Enterprise
NO <sub>2</sub>	Nitrogen Dioxide

PEF	Peak Expiratory Flow
PEFR	Peak Expiratory Flow Rate
PNOS	Particles not otherwise specified
SD	Standard Deviation
SO <sub>2</sub>	Sulfur Dioxide
SPSS	Statistical Package for the Social Science
TLV	Threshold Limit Value from American Conference of Governmental Industrial Hygienists
VC	Vital Capacity
XRD	X-ray Defraction

# Contents

<b>ACKNOWLEDGEMENTS.....</b>	<b>2</b>
<b>ABSTRACT.....</b>	<b>4</b>
<b>LIST OF PUBLICATIONS.....</b>	<b>7</b>
<b>ABBREVIATIONS.....</b>	<b>8</b>
<b>CONTENTS .....</b>	<b>10</b>
<b>1. INTRODUCTION .....</b>	<b>14</b>
<b>1.1. WHAT IS CEMENT? .....</b>	<b>14</b>
<i>1.1.1. Historical overview.....</i>	<i>14</i>
<i>1.1.2. Physical properties.....</i>	<i>14</i>
<i>1.1.3. Chemical composition.....</i>	<i>15</i>
<b>1.2. CEMENT PRODUCTION PROCESS .....</b>	<b>15</b>
<b>1.3. CEMENT INDUSTRY IN ETHIOPIA .....</b>	<b>17</b>
<b>1.4. CEMENT INDUSTRY IN THE WORLD.....</b>	<b>18</b>
<b>1.5. APPLICATIONS OF CEMENT .....</b>	<b>18</b>
<b>1.6. JOB GROUP AND DEPARTMENTS .....</b>	<b>18</b>
<i>1.6.1. Cleaners .....</i>	<i>19</i>
<i>1.6.2. Production workers.....</i>	<i>19</i>
<i>1.6.3. Security guards .....</i>	<i>24</i>
<b>1.7. GENERAL INFORMATION ON DUST EXPOSURE .....</b>	<b>24</b>
<b>1.8. EXPOSURE FROM GASES IN THE CEMENT INDUSTRY.....</b>	<b>26</b>
<b>1.9. OCCUPATIONAL DUST EXPOSURE IN THE CEMENT INDUSTRY .....</b>	<b>26</b>

---

1.10.	DIFFERENT RESPIRATORY HEALTH PROBLEMS IN THE CEMENT INDUSTRY RELATED TO DUST EXPOSURE.....	30
1.11.	ACUTE RESPIRATORY HEALTH EFFECTS.....	30
1.12.	CHRONIC RESPIRATORY HEALTH EFFECTS .....	30
2.	RATIONALE OF THE STUDY AND STUDY OBJECTIVES .....	34
2.1.	RATIONALE OF THE STUDY.....	34
2.2.	GENERAL OBJECTIVE .....	34
2.3.	SPECIFIC OBJECTIVES .....	35
3.	MATERIALS AND METHODS.....	36
3.1.	STUDY AREA.....	36
3.2.	STUDY DESIGN .....	37
3.3.	STATISTICAL POWER CALCULATIONS.....	38
3.4.	STUDY PARTICIPANTS.....	38
3.5.	ETHICAL CLEARANCE .....	39
3.6.	DATA COLLECTION.....	39
3.6.1.	<i>Interviews on acute respiratory symptoms (Paper I)</i> .....	39
3.6.2.	<i>Interviews on chronic respiratory symptoms (Paper III)</i> .....	40
3.6.3.	<i>Lung function tests</i> .....	41
3.6.4.	<i>Exposure measurement</i> .....	42
3.7.	STATISTICAL ANALYSIS.....	43
4.	SUMMARY OF RESULTS.....	45
4.1.	PAPER I.....	45
4.2.	PAPER II.....	46
4.3.	PAPER III.....	47

---

<b>5.</b>	<b>DISCUSSION.....</b>	<b>48</b>
5.1.	<b>METHODOLOGICAL DISCUSSION .....</b>	<b>48</b>
5.1.1.	<i>Study design .....</i>	<i>48</i>
5.1.2.	<i>Validity.....</i>	<i>49</i>
5.1.3.	<i>Questionnaire.....</i>	<i>53</i>
5.1.4.	<i>Exposure assessment.....</i>	<i>53</i>
5.1.5.	<i>Lung function testing.....</i>	<i>55</i>
5.2.	<b>MAIN DISCUSSION .....</b>	<b>56</b>
5.2.1.	<i>Occupational cement dust exposure.....</i>	<i>56</i>
5.2.2.	<i>Dust exposure and acute respiratory health effects .....</i>	<i>58</i>
5.2.3.	<i>Dust exposure and chronic respiratory health effects.....</i>	<i>59</i>
<b>6.</b>	<b>STUDY CONCLUSIONS .....</b>	<b>62</b>
<b>7.</b>	<b>RECOMMENDATIONS .....</b>	<b>63</b>
<b>8.</b>	<b>REFERENCES .....</b>	<b>64</b>
	<b>PAPERS I-III</b>	
	<b>APPENDICES IV &amp; V</b> <i>Questionnaire for acute and chronic respiratory symptoms</i>	



# 1. INTRODUCTION

## 1.1. What is cement?

### 1.1.1. Historical overview

The term *cement* was derived from the Latin word *caementum*, which means stone chippings that were used in Roman mortar (1). The origin of hydraulic cement goes back to ancient Greece and Rome where it was made from volcanic ash mixed with slaked lime (2, 3). The Roman Engineer Vitruvius described the surprising properties of this material; the mixture was able to set under water and the resistance increased with time, in a way completely different to any other material (4). Portland cement is a successor to hydraulic lime (5). The invention of Portland cement is usually attributed to Joseph Aspdin, who in 1824 took out a patent for a material that was produced from a mixture of limestone and clay. He called it “Portland” because the concrete made from it resembled natural stone from the Isle of Portland (2, 6). Since Roman times, cement is one of the synthetic materials with the largest production and usage by mankind. Its properties allowed the expansion of the Roman Empire and the building of fascinating works even today (4).

### 1.1.2. Physical properties

Portland cement is a fine gray powder, consisting of individual angular particles with a range of sizes (7, 8). Approximately 95% of cement particles are smaller than 45  $\mu\text{m}$ , with the average particle around 15  $\mu\text{m}$  (3, 9, 10). The particle density ranges from 3.10  $\text{g}/\text{cm}^3$  to 3.25  $\text{g}/\text{cm}^3$ , averaging 3.15  $\text{g}/\text{cm}^3$  (3). The pH of the cement in wet solution alkaline is within the range of 12.5-13.5 (2, 11).

### 1.1.3. Chemical composition

Portland cement is made up of four main compounds: tricalcium silicate ( $3\text{CaO} \cdot \text{SiO}_2$ ), dicalcium silicate ( $2\text{CaO} \cdot \text{SiO}_2$ ), tricalcium aluminate ( $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ ), and a tetra-calcium aluminoferrite ( $4\text{CaO} \cdot \text{Al}_2\text{O}_3\text{Fe}_2\text{O}_3$ ) (12-14). The percentage compositions of these compounds vary according to the type of cement required. Small amounts of uncombined lime and magnesia also are present, along with alkalis and minor amounts of other elements (15). Trace amounts of hexavalent chromium are very often present in the final product (12, 16). Portland cement dust has less than 1% crystalline silica (7).

## 1.2. Cement production process

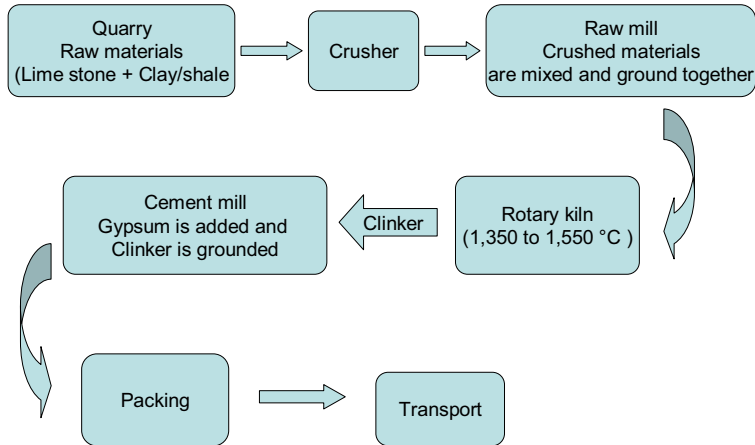
The main raw materials used in the cement production process are limestone, sand, shale, clay, and iron ore. The raw materials are usually mined on site or in nearby quarries. Mining of limestone requires the use of drilling and blasting techniques. The raw materials are loaded at the blasting face into trucks for transportation to the crushing plant.

The cement production process takes place in factories and involves crushing and grinding the raw materials, blending the materials in the correct proportions, burning the prepared mix in a kiln, and grinding the burned product, known as “clinker,” together with gypsum (Figure 1).

The raw materials are first crushed in the crusher and then usually grounded in a rotating cylindrical ball, or tube mills containing a charge of steel grinding balls. Then, proportioning of the chemical composition required for the particular cement is obtained by controlling the raw material fed to the crushing and grinding machines. Raw materials in some plants are sampled automatically, and a computer calculates and controls the raw mix composition. There are two different clinker manufacturing processes: dry and wet processes. In the dry process the mix of materials are stored in



silos. Thorough mixing of the dry materials in the silos is ensured by agitation and vigorous circulation induced by compressed air. The mix is then fed to the kiln for burning. In the wet process water is added to the raw materials to form a slurry. The slurry is mixed and blended to the correct chemical composition and then pumped to the kiln. The dominant means of burning is a rotary kiln. The kiln rotates slowly on an axis that is inclined a few degrees to the horizontal. The raw material is feed into the kiln at the upper end and moves slowly down the kiln to the lower or firing end. The fuel for firing may be pulverized coal, oil, or natural gas injected through a pipe. Cement production is a very energy consuming process. The temperature at the firing end ranges from about 1,350 to 1,550 °C, depending on the raw materials being burned. Some form of heat exchanger is commonly incorporated at the back end of the kiln to transfer heat to the incoming raw materials and thereby reducing the heat lost in the waste gases. The burned product emerges from the kiln as small nodules of clinker. These pass into coolers, where the product is cooled by cold incoming air. The clinker may be immediately ground to cement or stored in stockpiles for later use. Further, the clinker and the required amount of gypsum are ground to a fine powder in horizontal cement mills similar to those used for grinding the raw materials. The material may pass straight through the cement mill, or coarser material may be separated from the ground product and returned to the cement mill for further grinding. Finally finished cement is pumped pneumatically to storage silos from which it is later drawn for packing in paper bags (3, 17, 18).



**Figure 1** Cement production process flow chart

### 1.3. Cement industry in Ethiopia

Ethiopia's booming construction since 1990 across the country has placed a huge demand on cement. Currently, there are seven cement factories operating in the country and around 39 new factories are at various stages of investment, planning and development (19). However, three of the operating cement factories, namely Dire Dawa, Muger and Messebo have the major national market share with a combined production capacity of 1.7 million tons annually (20). The other cement factories, Abissinya, Dashen, Jemma and Koka commenced production recently and their combined annual production capacity is less than 400,000 tons. The available capacities are too small to meet the increasing demand for cement. Thus, more than 1/3 of the present cement consumption is imported (21). Dire Dawa, Muger and Messebo have rotary kilns with five-stage pre-heaters. The rest of the factories use vertical shaft kilns without any pre-heaters (20). In all of the factories the dry clinker manufacturing process is used.

## **1.4. Cement industry in the world**

In 2000 the world wide production of cement comprised of about 1.6 billion tons and 850,000 workers were employed in the cement industry (22). In the following years the world wide production of cement has increased, reaching an annual production of about 3 billion tons in 2008 (23).

## **1.5. Applications of cement**

Concrete is made up of three basic components: Water, aggregate (rock, sand, or gravel) and Portland cement. Cement, usually in powder form, acts as a binding agent when mixed with water and aggregates. This combination or concrete mix hardens into a durable material. Portland cement is used in concrete to construct pavements, floors, reinforced concrete buildings, bridges, tanks, reservoirs, pipes, masonry units, and precast concrete products. Mixtures of soil and Portland cement are used as a base for roads. Portland cement is also used in the manufacture of bricks, tiles, beams, railroad ties, and various extruded products. These products are fabricated in factories and supplied to the market.

## **1.6. Job group and departments**

Cement factories have different departments and job groups with various tasks. The departments in the cement production process usually include crusher, crane, raw mill, kiln, cement mill and packing. The job groups encompass cleaners, production workers, maintenance workers, office workers and security workers. The job groups, work tasks and departments included in this particular study are described in the following text.

### 1.6.1. Cleaners

- Cleaners (Figure 2) are found in all departments. They are involved in cleaning dust leakages from the machines. They perform cleaning of dust under and around the machines using manual broom and shovel. They remove the dust and fill it into wheelbarrows and put it back to the production line for reprocessing. The cleaners also assist maintenance workers when there is leakage due to failure of the machines.



**Figure 2** Cleaners in the packing department (*Photograph by Zeyede K*)

### 1.6.2. Production workers

Workers in the production are mainly localized in five departments (crusher, crane, raw mill, kiln and packing). The job groups mainly include operators, attendants, packers and loaders. The work tasks vary according to the respective departments.

- **Crusher:** Crusher machine workers include operators in the control room who periodically check when raw materials are poured into the crusher (Figure 3). Belt attendants are responsible for attending the belt for smooth flow of crushed raw materials. The dozer operators load the raw material from the

quarry site to the dumper trucks while dumper operators dump the raw material into the crusher machine (Figure 3).



**Figure 3** Dumping of raw material into the crusher machine (*Photograph by Zeyede K*)

- **Crane:** The crane operators (Figure 4) rearrange stored materials from the crusher and feed the hoppers that are connected to the mills. The attendants are responsible in ensuring that the pavement and the crane in the gantry are clean, and also ensure that materials that failed to enter the hoppers are pushed into it.



**Figure 4** A crane operator on duty inside the cabin rearranging stored materials (*Photograph by Zeyede K*)

- **Raw mill:** The major activities in the raw mill department are raw material proportioning, homogenization and size reduction of raw material prior to the calcination process (Figure 5). The raw mill operators monitor the process from the control room, and sometimes visit the process outside. Raw mill attendants ensure the smooth running of machines in the department and are always in the production area.



**Figure 5** A raw mill attendant in the raw material proportioning section  
(*Photograph by Zeyede K*)

- **Kiln** In this department the attendants are responsible to attend the smooth running of different machines such as the pre-heater, rotary kiln and the cooler. The operator works in the control room, monitors all stages of the process and also visits the process for shorter periods of time (Figure 6).



**Figure 6** Kiln operator while on periodic check of the process (*Photograph by Zeyede K*)

- **Packing** In this department packers put cement bags on the packing machine for filling (Figure 8), while others handle stored empty bags and ensure the smooth running of filled cement bags on the conveyor belts (Figure 7). Loaders load filled bags into trucks (Figure 9).



**Figure 7** Filled cement bags on the conveyor belt (*Photograph by Zeyede K*)



**Figure 8** Cement packer in the packing department (*Photograph by Zeyede K*)



**Figure 9** Cement loaders in the packing department (*Photograph by Zeyede K*)



### **1.6.3. Security guards**

Security workers are responsible for guarding the compound of the factory. They stay mainly outside the plant. They served as a control group in the present study as their dust exposure was considered to be low.

## **1.7. General information on dust exposure**

Cement dust consists of solid particles which can be made airborne by the mechanical disintegration of bulk solid material (e.g. during cutting, crushing, grinding, abrasion and transportation) (24). Deposition of inhaled material in the airways is primarily dependent on particle size and is best described by the aerodynamic diameter. The aerodynamic diameter is the diameter of spherical particles of unit density which have the same falling velocity in air as the particle in question (24). Deposition of dust particles within the respiratory system also varies with the geometry of the air passages and the patterns of airflow. Particle deposition in the respiratory system is caused by combined mechanisms of gravitational sedimentation, Brownian diffusion mainly in small airways and inertial impaction mainly in large airways (23). The respirable dust fraction refers to the mass fraction of inhaled particles which penetrate to the alveoli (50% cut-off point at 4  $\mu\text{m}$ ), the thoracic dust fraction refers to the mass fraction that enters the tracheo- bronchial region (50% cut-off point at 10  $\mu\text{m}$ ) and the inhalable dust fraction refers to the mass fraction that enters the mouth and nose (50% cut-off point at 100  $\mu\text{m}$ )(24).

Dust mass can be measured quantitatively by gravimetric analysis. Dust concentrations can be calculated from the change in weight of a filter from after to before sampling divided by the volume of air moving through the filter. Personal dust samplers are used to conduct respirable, thoracic, inhalable or total dust sampling. Samples of total and respirable dust can be collected on filters placed in for instance closed-faced "Millipore" plastic cassettes and in respirable cyclones, respectively.

---

Results of measurements on isolated samplers under calm air conditions have shown that for instance GK2.69, the modified SIMPEDS cyclones, the IOM thoracic sampler and the modified IOM inhalable sampler with a foam plug insert agree well with the thoracic convention (25). Compared to the ISO/CEN related sampling efficiency convention for inhalable dust particles, the closed-faced Millipore total dust sampler has a lower sampling efficiency for particle sizes greater than 30µm. Thus, the results from personal sampling using the closed faced Millipore cassettes underestimate the inhalable fraction of the dust (26). The IOM cassette, which is designed to collect the inhalable fraction of the aerosol, collects 1.5 to 3.0 times as much aerosol by mass as the Millipore sampler (27).

Misclassification of exposure could bias the validity of association between exposure and health effects. Therefore, in order to avoid possible bias it is important to determine the exposure level as well as the within and between worker components of variability during their work. Factors which contribute to the variances include type of exposure, task performed and other production and environmental characteristics (28-30). Environmental characteristics such as presence of rain and outdoor wind speed may affect cement dust exposure (31). Another factor is the day to day variability in time spent on specific tasks. Variability in exposure from day to day and between workers comprising an occupational group can be used to assess probabilities of overexposure and exceedance relative to occupational exposure limits (30), to classify workers into similar exposure groups (32) and to examine homogeneity in exposure levels. Kromhout et al. (28) found high within worker (day-to-day) variability during outdoor work and among those working without local exhaust ventilation. In that study, groups consisting of mobile workers and those working with an intermittent process also showed great day-to-day variability. Hence environmental and production factors were shown to have distinct influences on the within worker variability (28). Between-worker variability within a job group is difficult to predict based on general environmental and production characteristics (28). Between-worker variability is often influenced by factors like work style and the mix of tasks performed (30). In a previous study of cement workers, Mwaselage

et al found lower between-worker variability than within-worker variability in different job categories where workers performed more or less similar tasks (33).

## **1.8. Exposure from gases in the cement industry**

The presence of gases such as NO<sub>2</sub> and SO<sub>2</sub> represent another exposure in cement factories that may cause adverse respiratory health effects (34). SO<sub>2</sub> is formed as a result of the sulfur content in the coal burned in the kilns. NO<sub>2</sub> is formed in the kiln by the oxidation of nitrogen compounds present in the fuel or by direct oxidation of atmospheric nitrogen at high temperatures.

The concentrations of SO<sub>2</sub> and NO<sub>2</sub> in the work place atmosphere can be measured by the Dräger detector tubes (35) or by direct reading electrochemical sensors.

## **1.9. Occupational dust exposure in the cement industry**

Cement workers are exposed to dust at the various production processes. There are several studies of cement dust exposure among process operators and machine attendants. A list of studies on cement dust exposure published in scientific journals the last 15 years (except for one American study published 23 years ago) is shown in Table 1. Higher dust exposure has been reported in developing countries such as Tanzania, Ethiopia, Iran and Saudi Arabia (33, 36-38) than in USA and Norway (39,40). This difference might be caused by established regulatory actions and more advanced technical control measures in the cement industry in industrialized countries than in developing countries.

The measured dust levels in the studies (Table 1) also varied by departments, and the highest total dust exposure was found in the crane followed by packing and crusher in Tanzania (33); in packing in Malaysia (41) and in calcining followed by packing in

Lithuania (42). The highest respirable dust level was in the packing department in Ethiopia (43) and in the quarry followed by the raw mill in Saudi Arabia (38, 44).

Mwaiselage et al. (33) reported that the concentration of respirable dust by mass was approximately 40% of the total dust in a Tanzanian cement factory. This indicates that, in terms of mass, the coarser particles dominate in the cement factories.

Peters et al. 2009 found that dust concentrations in cement production plants, especially during cleaning tasks, are considerably higher than at construction sites (31). To our knowledge there is only one previous study conducted among cement cleaners to characterize the dust exposure. In this study the thoracic dust levels were measured among cleaners as a sub-group (45).

**Table 1 Studies on total and respirable cement dust exposure levels in different sections of cement factories by country and year of publication**

Author <sup>[ref]</sup> and year	Country	Department	Number of samples	Respirable dust (mg/m <sup>3</sup> )			Number of samples	Total dust (mg/m <sup>3</sup> )			% of samples exceeding TLV	
				AM	GM	Range		AM	GM	Range	Respirable dust (TLV=5mg/m <sup>3</sup> )	Total dust (TLV=10mg/m <sup>3</sup> )
Abrons et al <sup>[39]</sup> 1988	USA	All	1011	0.57	-	.01-46.2	211	2.9	-	.01-78.6	5	19
Yang et al <sup>[69]</sup> 1996	Taiwan	All	147	-	3.58	1.28-8.12	-	-	-	-	-	-
Abudhaise et al <sup>[54]</sup> 1997	Jordan	Raw mill	129	-	0.5	-	-	-	-	-	-	-
		clinker Finishing	99	-	1.6 3.9	-	-	-	-	-	-	-
Abrons et al <sup>[58]</sup> 1997	USA	All	2298	0.9	-	-	1044	7.5	-	-	-	-
Mengesha et al <sup>[36]</sup> 1998	Ethiopia	Kiln	4	3.24	-	-	-	-	-	-	-	-
		Packing	7	43.1	-	-	-	-	-	-	-	-
Noor et al <sup>[41]</sup> 2000	Malaysia	Packing1	-	-	-	-	62	10.2	-	-	-	-
		Packing2	-	-	-	-	6.9	-	-	-	-	-
		Cement mill	-	-	-	-	2.8	-	-	-	-	-
		Quarry	-	-	-	-	.004	-	-	-	-	-
Ballal et al <sup>[38]</sup> 2004	Saudi Arabia	Kiln	-	-	-	-	-	3.3	-	-	-	-
		Quarry	29	20.3	13.3-59.5	-	-	-	-	-	100	-
		Raw mill	25	15.2	4.3-47.6	-	-	-	-	-	96	-
		Packing	20	14.8	4.8-25.8	-	-	-	-	-	95	-
		Kiln	15	7.1	2.13-22.2	-	-	-	-	-	80	-
		Cement mill	8	10.6	7.1-16.7	-	-	-	-	-	100	-
		Crusher	7	19.3	1.5-70.2	26	18.94	13.48	21-63.07	-	-	84.61
		Packing	6	7.9	2.0-20.8	17	38.97	21.30	3.19-229.2	-	-	76.47
Mwaiselage et al <sup>[33,48]</sup> 2005	Tanzania	Chanes	7	12.8	1.7-71.2	12	54.73	38.64	8-139.76	-	-	91.67
		Kiln	4	1.5	.7-5.0	8	4.11	2.87	1.9-94	-	-	0
		Raw mill	-	-	-	8	2.18	1.85	.80-3.66	-	-	0
		Cement mill	-	-	-	8	4.21	3.23	1.25-8.27	-	-	0
		Maintenance	-	-	-	24	2.07	1.16	.11-10.23	-	-	0
		Administration	-	-	-	17	0.59	0.29	.01-2.36	-	-	0
Neghab et al <sup>[37]</sup> 2007	Iran	All	88	26	-	-	-	-	-	-	-	

Smalilyte et al <sup>[42]</sup> 2004	Lithuania (1995-2000)	Calcining Milling Packing Repair	- - - -	- - - -	- - - -	- - - -	- - - -	17.1 11.2 15 3.7	- - - -	- - - -	- - - -	- - - -
Peters et al <sup>[31]</sup> 2009	Germany	Cement plant Cleaning	- -	- -	- -	- -	19 6	7 98	3 55	0.35-52 (Inhalable) 8.8-194 (Inhalable)	- -	- -
Fell et al <sup>[40]</sup> 2003	Norway	All	20	0.91	-	0.0-2.3	20	7.4	-	0.4-53.7	0	15
Ali et al <sup>[44]</sup> 1998	Saudi Arabia	Quarry Raw mill Packing Kiln Cement mill	29 25 20 15 8	- - - - -	20.28 13.2 14.83 7.1 10.57	13,29-59.5 4,25-47.62 4,81-25.79 2,13-22.17 7,09-16.67	- - - - -	- - - - -	- - - - -	- - - - -	29 24 19 12 8	- - - - -
Nordby et al <sup>[45]</sup> 2011	Estonia Greece Italy Norway Spain Sweden Switzerland Turkey	All	2670	-	0.85 (Thoracic dust fraction)	-	-	-	-	-	-	-

Note: AM: Arithmetic mean, GM: Geometric mean, TLV: Threshold Limit Value refers to 10 mg/m<sup>3</sup> for inhalable particles not otherwise specified (PNOS)

## **1.10. Different respiratory health problems in the cement industry related to dust exposure**

The most commonly reported respiratory health problems in cement factories are chronic respiratory symptoms, such as chronic cough and phlegm production, chest tightness and wheezing. Impairment of lung function like specific obstructive lung disease is also commonly reported (7, 46) Carcinoma of laryngeal and lung cancer have also been reported (16, 42, 47) but, will not be discussed further in the thesis.

## **1.11. Acute respiratory health effects**

Acute respiratory health effects refer to acute changes in respiratory health status immediately following an exposure. This kind of effects can for instance be determined by interview of respiratory symptoms experienced among workers immediately after the work shift and by measurement of their lung function before and after the work-shift. Cement dust exposure has been found to be related to acute respiratory symptoms and acute changes in lung function. The pathogenesis is probably due to its irritative properties (6). Two studies, one in Tanzania and one in Ethiopia (Table 2), found higher prevalence of acute respiratory symptoms and cross-shift reductions in Peak Expiratory Flow in cement workers (44, 48). One study in Saudi Arabia found greater post-shift reductions in FEV<sub>1</sub> and in the FEV<sub>1</sub>/FVC ratio in exposed cement workers compared to controls (44).

## **1.12. Chronic respiratory health effects**

Chronic respiratory health effects may be defined as respiratory health problems lasting three months or more. Table 2 summarizes the studies on prevalences of chronic respiratory symptoms and measurements of lung function published the last 25 years (except one prospective Yugoslavian study published 35 years ago).

Several cross sectional studies have found high prevalence of chronic respiratory symptoms (7, 38, 41, 49-54) and reduction of lung function (7, 41, 53, 55-57). Increased prevalence of radiography-detected minor abnormalities of lungs (58, 59) has been also reported among workers in the cement industry. However, no difference in respiratory health between cement workers and controls was also reported in some studies (40, 60, 61).

As far as we know there are only few prospective cohort studies among cement workers and these studies found reductions in lung function (62, 63).



**Table 2 Overview of studies on prevalence of chronic respiratory symptoms and lung function changes among exposed cement workers by country and year of publication**

Author and year <sup>[ref]</sup>	Country	Study design	Exposed (n)	Controls (n)	All (n)	Prevalence of respiratory Symptoms (%)	Lung function changes Among exposed
Mwaiselage et al. <sup>[48]</sup> 2005	Tanzania	Cross-shift	51	33		Cough (41 vs 6), shortness of breath (43 vs 9), stuffy nose (78 vs 39) runny nose (39 vs 15), sneezing (61 vs 33)	↓ Δ PEF <sub>50%</sub>
Ali et al. <sup>[44]</sup> 1998	Saudi Arabia	Cross-shift	149	348			↓ Δ FEV <sub>1</sub> , ↓ Δ FEV <sub>1</sub> /FVC, and ↓ Δ PEF <sub>25-75%</sub>
Yang et al. <sup>[49]</sup> 1996	Taiwan	Cross sectional	412	147		Cough (19 vs 12), Phlegm (18 vs 13), wheezing (8 vs 6), Dyspnea (9 vs 7)	↓ FVC, ↓ FEV <sub>1</sub> , ↓ FEF <sub>50</sub> , and ↓ FEF <sub>75</sub>
Mengesha et al. <sup>[43]</sup> 1997	Ethiopia	Cross sectional	53	211		Chronic cough (30 vs 9), chronic bronchitis (26 vs 10), bronchial asthma (32 vs 9)	↓ FEV <sub>1</sub> , ↓ FEF, ↓ FMF <sub>25-75%</sub> and ↓ PEFR
Noor et al. 2000 <sup>[47]</sup>	Malaysia	Cross sectional	62	70		Morning cough (25 vs 6), morning phlegm (24 vs 11), chest tightness (19 vs 6)	↓ FVC, ↓ FEV <sub>1</sub> , ↓ FEV <sub>1</sub> % and ↓ FEF <sub>25-75%</sub>
Al-Neaimi et al. <sup>[50]</sup> 2001	United Arab Emirates	Cross sectional	67	134		Cough (30 vs 10), phlegm (25 vs 5), wheeze (8 vs 3), dyspnea (21 vs 5), sinusitis (27 vs 11), bronchitis (13 vs 4), Asthma (6 vs 3)	↓ VC, ↓ FVC, ↓ FEV <sub>1</sub> and ↓ PEF
Mwaiselage et al. <sup>[48,57]</sup> 2004, 2005	Tanzania	Cross sectional	120	107		Chronic cough (26 vs 12), chronic sputum production (34 vs 10), dyspnea (19 vs 7), chronic bronchitis (20 vs 8)	↓ FVC, ↓ FEV <sub>1</sub> and ↓ PEF
Neghab M et al. <sup>[57]</sup> 2007	Iran	Cross sectional	88	80		Cough (32 vs 20), wheezing (28 vs 5), breathlessness (17 vs 5), phlegm (26 vs 15)	↓ VC, ↓ FVC, ↓ FEV <sub>1</sub> , ↓ FEF <sub>25-75%</sub> , and ↓ PEF
Alakija et al. <sup>[55]</sup> 1990	Nigeria	Cross sectional			477		↓ FVC, ↓ FEV <sub>1</sub> and ↓ PEF (For workers >15 yr service)
Ballal et al. <sup>[48]</sup> 2004	Saudi Arabia	Cross sectional	150	355		Dyspnea (23 vs 13), acute bronchitis (35 vs 13), bronchial asthma (11 vs 3)	

Abou-Taleb et al <sup>[46]</sup> 1995	UAE	Cross sectional			304	Chronic cough (19), Chronic bronchitis(12), but no control for comparison	↓ FVC and ↓ FEV <sub>1</sub> in packers than loaders
Oleru <sup>[7]</sup> 1984	Nigeria	Cross sectional	52	24		Cough and phlegm (89 vs 63), chest-tightness (81 vs 38), Dyspnea (54 vs 0)	No difference in FEV <sub>1</sub> , FVC
Abudhaise et al <sup>[54]</sup> 1997	Jordan	Cross sectional	348	189		Chronic cough (16 vs 2), chronic dyspnea (17 vs 10), chronic wheezing (7 vs 3), asthma (13 vs 2)	FEV <sub>1</sub> /FVC, FEV <sub>2.5-75%</sub>
Abrons et al <sup>[97]</sup> 1988	USA	Cross-sectional	2736	755		Similar prevalence except dyspnea (5 vs 3)	No difference in FVC, FEV <sub>1</sub> , PF, FEF <sub>50</sub> , FEF <sub>75</sub>
Laraqui et al <sup>[51]</sup> 2002	Morocco	Cross-sectional	280	73		Cough (56 vs 19), expectoration rhinitis(53 vs 25), chronic bronchitis (49 vs 26) and asthma (29 vs 7)	↓ VC, ↓ FEV <sub>1</sub> and No difference
Merenu et al <sup>[56]</sup> 2007	Nigeria	Cross-sectional	56	96			↓ VC, ↓ FEV <sub>1</sub> and No difference in FVC and PEF
Nordby et al <sup>[65]</sup> 2011	8 countries in Europe	Cross-sectional	3495 <sup>a</sup>	3495 <sup>b</sup>		wheezing + dyspnea OR:2.6 (1.6-4.4), wheezing + dyspnea + coughing OR:2.3 (1.3-4.4)	↓ FVC, ↓ FEV <sub>1</sub> , ↓ FEV <sub>1</sub> /FVC(highest quartile vs lowest)
Fell et al.2003 <sup>[60]</sup>	Norway	Retrospective cohort	119	50		No difference in morning cough, dyspnea, occasional wheezing, chronic cough	No difference in FVC, FEV <sub>1</sub> and FEV <sub>1</sub> /FVC
Saric et al. 1976 <sup>[62]</sup>	Yugoslavia	Prospective cohort	160	80			↓ FVC, ↓ FEV <sub>1</sub> and ↓ FEV <sub>1</sub> /FVC
Siracusa et al <sup>[63]</sup> 1988	Italia	Prospective cohort	68				↓ FVC and ↓ FEV <sub>1</sub>

OR: Odds ratio (95% confidence interval), <sup>a</sup> Highest quartile (Exposure>1.74mg/m<sup>3</sup>), <sup>b</sup> Lowest quartile (Exposure<0.49mg/m<sup>3</sup>)

## **2. Rationale of the study and study objectives**

### **2.1. Rationale of the study**

To date, most of the studies performed on respiratory symptoms and lung function of cement workers are cross-sectional. There are very few longitudinal studies making the causal relationship between cement dust exposure and respiratory health effects uncertain. Further knowledge on the topic is needed worldwide for cement workers, to be able to implement correct interventions.

The industrial development strategy of Ethiopia, which has recently been launched by the Government, encourages labor-intensive industries. Cement industry is among the sectors which are given priority in the industrial development strategy and a large number of workers will be related to this type of work also in the future. Despite the importance of cement to the Ethiopian economy, little information exists on the cement dust exposure and respiratory health of cement workers in this country. Two studies from the Ethiopian cement industry were published in 1996 and 1997, but these studies had very few exposure measurements. As most previous studies worldwide in cement industries, the two Ethiopian studies were studying machine attendants and operators only. Studies on cement cleaning workers are largely missing. Therefore, in Ethiopia, information on respiratory health among the highest exposed cement workers and particularly on cement cleaners is clearly needed.

### **2.2. General objective**

The general objective of this study was to assess dust exposure and respiratory health problems among workers in cement factories in Ethiopia.

### **2.3. Specific objectives**

- To assess personal exposure to dust among production workers in cement factories in Ethiopia, with particular focus on cement cleaners.
- To investigate acute respiratory health effects among cement factory workers.
- To perform a one year follow-up study on chronic respiratory symptoms and lung function among cement factory workers and controls.

### 3. Materials and Methods

#### 3.1. Study area

This study was conducted in three cement factories in Ethiopia (Figure 10). Dire Dawa cement factory (1) is located 500 km east of the capital, Addis Ababa. The production capacity in 2005 was about 34,000 tons of cement per year and run by 320 workers. The factory commenced production in 1945. Muger Cement Enterprise (MCE) (2) is located west of the capital. In 2009 it had about 1336 workers. It has operated at a capacity of 600,000 tons of cement per year since 1984. Messebo (3) is situated north of the capital. The annual production capacity is 630,000 tons of cement and the factory had 740 employees in 2009. It started the production in 2001.



**Figure 10** Map of study areas and location of cement factories

## 3.2. Study design

We conducted studies with cross sectional, cross-shift and cohort designs. Data was collected in three periods. Paper I is based on a questionnaire survey on acute respiratory symptoms, pre-shift and post-shift Peak Expiratory Flow (PEF) and personal total dust exposure measurements in Dire Dawa cement factory. The second paper describes repeated measurements of total and respirable dust among selected workers in Mughher and Messebo cement factories. In paper III, a one year follow up study was carried out in the same factories as in paper II. Lung function, chronic respiratory symptoms and measurement of personal total dust exposure were conducted at baseline in 2009 and at follow up in 2010 (Table 3).

**Table 3 An overview of the study designs, year of study and the assessments performed in three papers in the cement industry**

Study design	Paper	Year	Factory	Exposure	Respiratory symptom	Lung function
Cross-sectional & Cross-shift	I	2005	Dire Dawa	Total dust	Acute	PEF
Cross-sectional	II	2009	Mughher and Messebo	Total dust and Respirable dust	-	-
Longitudinal	III	2009& 2010	Mughher and Messebo	Total dust	Chronic	FEV <sub>1</sub> , FVC, FEV <sub>1</sub> /FVC

### 3.3. Statistical power calculations

In Paper I, 40 exposed workers and 20 less exposed controls were included. This sample size provided 88% power to detect a difference of 15 l/min between the groups for paired observation of cross-shift PEF at  $P < 0.05$  (48).

In the Tanzanian cement industry Mwaiselage et al. (57) found an annual decline in FEV<sub>1</sub> of 49.1 ml for an average worker exposed to 28.9 mg/m<sup>3</sup> per year. Based on that study we estimated that for our follow-up study (paper III) 20 individuals in the exposed groups would be sufficient to detect a decline in FEV<sub>1</sub> of 51ml/s per year (SD=80) with a power of 80 % at  $P < 0.05$ . The followed-up workers in the exposed groups were 38 cleaners and 33 production workers.

### 3.4. Study participants

In paper I, the exposed group included all workers from the crusher ( $n = 20$ ) and packing sections ( $n = 22$ ) from one cement factory. These workers were selected as they were presumed to represent the highest dust exposed areas. The guards of the factory were presumed to be low exposed as they were working outside the factory. In the packing section, one worker did not volunteer to participate in the study and one worker was not on duty, thus leaving 20 workers from the packing section in the final study population.

In paper II, 105 workers from two factories were randomly selected for personal measurements of total dust. Forty-five of these workers were randomly re-selected for repeated measurement of total dust. 30% of the selected workers in four departments (crusher, raw mill, kiln and packing) were also sampled for respirable dust in parallel with total dust sampling. During the field work of Paper II, in 2009, 127 randomly selected workers from the two factories were invited and examined for lung function and interviewed for chronic respiratory symptoms (Paper III). At baseline in 2009 the

participants in Paper III comprised 56 cement cleaners, 44 cement production workers and 27 controls (security workers).

In Paper III, 91 workers (38 cement cleaners, 33 cement production workers and 20 controls) out of the 127 workers examined at baseline in 2009 were reexamined for lung function and interviewed for chronic respiratory symptoms in 2010. Thus, the follow up time for these 91 workers was 1 year. Forty six of these workers were also randomly selected for measurements of personal total dust in 2010.

### **3.5. Ethical clearance**

The proposal was granted ethical clearance by the Regional Committee for Medical Research Ethics of Western Norway and the Regional Medical Research Committee in Oromia and Mekelle Health Bureau of Ethiopia. Permission to conduct the study was also given from the management of the factories. Written consent was obtained from each worker before enrollment into the study.

### **3.6. Data collection**

#### **3.6.1. Interviews on acute respiratory symptoms (Paper I)**

During the data collection for paper I, all study participants were interviewed by one person only using a standardized set of questions. The interview questionnaire was a combination of the British Medical Research Council's (BMRC) questionnaire (64) and the modified Optimal Symptom Score questionnaire (65). The questionnaire was translated from English to Amharic and back-translated to English according to standard procedures.



The questions on personal and work characteristics included years of education, years in other industry, years in different sections of the cement factory, use of respiratory protective gear, past respiratory diseases and smoking habits. Participants were asked to rate their symptom experiences from the time they began work that day to immediately after the morning work shift the same day. The questions asked how they perceived the severity of the symptoms on a 5-point scale as never (1), mild (2), moderate (3), severe (4) or very severe (5). The acute symptoms recorded were cough, shortness of breath, stuffy nose, wheezing, runny nose and sneezing. Smoking was recorded as "yes" for current smokers and "no" for nonsmokers and ex-smokers. Before statistical analysis, the five point acute respiratory symptom score was dichotomized into "no" for those who scored never and "yes" for those who scored mild, moderate, severe or very severe. Education was dichotomized into primary for those with grade 4 or less and post-primary for those with grade 5 or more.

### **3.6.2. Interviews on chronic respiratory symptoms (Paper III)**

Questionnaire interviews on chronic respiratory symptoms in paper III were carried out during the data collection periods in 2009 and 2010 by one person only. The questionnaire was derived from the modified British Medical Research Council's questionnaire (64). The questionnaire was translated into Amharic using the same standard procedure of translation and back-translation. The questionnaire included personal and work characteristics such as age, educational level, employment history, previous illness, years worked in the cement factory and years worked in dusty industries elsewhere. Workers were asked about their smoking habits. Current smokers were defined as those who smoked at the time of the study or had stopped smoking less than one year ago. Ex-smokers were those who had quite at least 1 year before the survey. Further, the workers were asked whether they had ever experienced illnesses like asthma, tuberculosis, chest injury/operation, abnormalities of the vertebral column/thoracic cage or any other severe debilitating disease such as heart conditions, diabetes mellitus, anemia or neuromuscular diseases. Those with any of these problems ever or now were excluded from the analysis. The questions on

---

chronic respiratory symptoms (yes/no) included chronic cough, chronic sputum production, shortness of breath, wheezing and chest tightness. After the shift the workers were interviewed about their use of respiratory protective devices. The same questionnaire was used during both data collection periods (2009 and 2010) to document changes in respiratory health of the workers.

### **3.6.3. Lung function tests**

In Paper I, PEF was measured among all workers interviewed for acute respiratory symptoms. PEF was recorded using a portable handheld Mini-Wright PEF meter (Clement Clarke International, Essex, UK). PEF was measured at their workplace within 20 minutes before the shift and within 20 minutes after the shift. The method was demonstrated to each worker. Acceptability and reproducibility were in compliance with the American Thoracic Society guidelines (ATS) (66) and European Respiratory Society recommendations (67). The highest value of three successive technically correct blows was recorded as the final result. All PEF measurements were performed while the participants were standing, and the maximum recorded value in liters/minute was used in the analysis. The percentage acute cross-shift change in PEF was calculated as  $[(\text{postshift PEF} - \text{preshift PEF})/\text{preshift PEF}] \times 100$ .

In Paper III, spirometric measurements were performed during the field work in 2009 and 2010 using a digital Spirare spirometer (SPS310).

The procedures for the ventilatory function test were explained individually to the workers and the ATS recommendations (66) were followed except for that the subjects were examined in a sitting position and they were not using nose clip. Spirometry was performed before the morning shift. The maximum FEV<sub>1</sub>, FVC, and the percentage ratio of FEV<sub>1</sub>/FVC were recorded. The standing height and weight of each subject was measured before shift in normal working clothes. The same spirometer and techniques were used both in 2009 and 2010.

### **3.6.4. Exposure measurement**

#### *3.6.4.1. Dust exposure*

We conducted personal exposure measurements three times. In Paper I and III total dust was sampled. In Paper II both respirable and total dust were sampled. In Paper I, 50 personal total dust measurements were conducted; 20 from crusher, 20 from packing and 10 from the controls. In Paper II, 150 personal measurements of total dust from 105 randomly selected workers in four departments were performed (forty five workers had two measurements each). Thirty six samples of respirable dust were also taken for about 30% of the selected workers in four departments (crusher, raw mill, kiln and packing). Of these 36, a total of 16 randomly selected respirable samples were analyzed for crystalline silica from four departments (4 samples from each department).

The number of total dust samples in Paper II and III were in accordance with Rappaport and Kupper who suggested that 10-20 measurements per observational group (i.e., two measurements from 5-10 randomly selected persons) should generally be sufficient for initial assessments of exposure levels (68). During the second field work for Paper III in 2010, 112 personal measurements of total dust were taken from 46 workers (1-2 measurements per worker for the production workers and 2-4 measurements per worker for the cleaners).

Total and respirable dust samples were collected on 37 mm cellulose acetate filters with a pore size of 0.8  $\mu\text{m}$  placed in closed-faced Millipore cassettes and in SKC conductive plastic respirable cyclones, respectively. The cassettes and cyclones were attached to pumps (SKC Side Kick) at flow rates of 2 l/min and 2.2 l/min, respectively. A rotameter was used to adjust the flow. The cement dust was measured quantitatively by gravimetric analysis on a microbalance scale (Mettler AT261), with a detection limit of 0.01  $\text{mg}/\text{m}^3$  at X lab AS (Bergen, Norway), which has passed the Norwegian inter-calibration test for dust sample analysis (Paper I) and in an ISO-certified laboratory (Eurofins, Denmark) (Paper II and III). Crystalline silica in

---

respirable dust samples was measured using X-ray diffraction (XRD) technique with a limit of detection of 5µg/filter (Paper II). We have compared exposure levels with ACGIH's TLV-values since they are suggested to be health related (69).

#### 3.6.4.2. *Gas exposure*

In Paper III, ten measurements each for SO<sub>2</sub> (5 in each plant) and NO<sub>2</sub> (5 in each plant) in the work area near the kiln were taken using Dräger tubes. The Dräger accuro pump was used to draw a calibrated 100 ml of air sample through the Dräger-Tubes. The measuring ranges for the tubes were: 0.5-25 ppm for SO<sub>2</sub> (No 6728491) and 0.5 - 25 ppm for NO<sub>2</sub> (No CH30001), respectively. The samples were taken every other day for 5 days in each factory (Range: 24 to 30 hours between two consecutive measurements).

### 3.7. Statistical analysis

Data were analyzed using SPSS version 12 (Paper I) and version 15 (Paper II and III).

Groups were compared using several statistical methods as summarized in Table 4. Categorical variables were described by number and percentages. Continuous variables were described by arithmetic mean (AM), range, geometric mean (GM), and geometric standard deviation (GSD).

Differences in socio-demographic data and respiratory symptoms between groups were analyzed using chi-square test or Fisher's exact test for categorical variables, and student's t-test and ANOVA for continuous variables.

Wilcoxon signed ranks test was used to analyze changes in chronic respiratory symptoms between baseline in 2009 and follow up. Dependent t test was used to analyze changes in lung function indices during the one year follow up period (Paper III).

The relationship between exposure and PEF was analyzed using multiple linear regression (Paper I). Multiple linear regression was also used to compare differences in lung function values between group of workers adjusting for age and height (Paper III).

Exposure data were log-normally distributed and analyses were performed on  $\log_e$  transformed data.

To establish determinants of dust exposure, linear mixed effect models were developed for total dust using the individual worker as a random factor; while plants, distance from the machines and time fraction were fixed factors (Paper II).

Using workers ID as a random factor, the within-worker ( $ww\delta$ ) and between-worker ( $bw\delta$ ) variance components were estimated using random effects and mixed effects models (Paper III).

**Table 4 Statistical methods used in the analysis**

Paper	I	II	III
Chi-square/Fisher's exact test	x	-	x
Pearson's correlation	x	-	-
Independent t-test	x	x	x
Dependent t-test	x	-	x
ANOVA	x	x	x
Linear multiple regression	x	-	x
Linear mixed effect model	-	x	x
Wilcoxon signed ranks test	-	-	x

## 4. Summary of results

### 4.1. Paper I

The association between cement dust exposure and acute respiratory health was investigated among 40 dust-exposed cement workers from the crusher and packing and 20 controls from the guards. The two groups comprised only men and did not differ in education, employment duration, height or current smoking. However, the exposed workers were significantly younger (mean age 29 years) than the controls (40 years). The highest geometric mean dust exposure was found in the crusher section ( $38.6 \text{ mg/m}^3$ ) followed by the packing section ( $18.5 \text{ mg/m}^3$ ) and the guards ( $0.4 \text{ mg/m}^3$ ). Within each of these sections exposure was highest during cleaning tasks. In the crusher and packing sections, 95% and 60% of the "total" dust samples exceeded the TLV of  $10 \text{ mg/m}^3$ , respectively. The exposed workers had significant higher prevalence of stuffy nose (85%), shortness of breath (47%) and sneezing (45%) than controls. Cross-shift change in PEF declined in the exposed groups ( $P = 0.003$ ), whereas cross-shift change in PEF increased among the controls ( $P = 0.004$ ). The percentage change in PEF ( $\Delta\text{PEF}\%$ ) across the shift differed significantly between the groups. A regression model including the number of years in exposed sections (packing and crushing), current smoking and log-"total" dust exposure explained 25.4% ( $R^2_{\text{adj}}$ ) of the variability in the percentage cross-shift change in PEF. Height and age were not significantly associated with cross-shift PEF in the multiple regression and were not included in the final model. Age was not correlated with the number of years in high exposed sections, but age and preshift PEF were negatively correlated.

## 4.2. Paper II

This paper characterized personal exposure to total and respirable dust among production workers in two cement factories (A and B) with particular focus on cleaners. In both factories, cleaners had significant higher exposure to total dust than other production workers (geometric means  $549 \text{ mg/m}^3$  vs.  $3.9 \text{ mg/m}^3$  in Factory A; and  $153 \text{ mg/m}^3$  vs.  $10.2 \text{ mg/m}^3$  in Factory B, respectively). Among the cleaners, the total dust exposure in factory A was significant higher than in Factory B ( $p < 0.001$ ). The fractions of respirable dust samples that exceeded the TLV of  $1 \text{ mg/m}^3$  for Portland cement dust were 85% among cleaners and 80% among other workers, respectively.

The temporal (day to day) variability dominated the variability in total dust exposure for cleaners. Among the cleaners, working in either Factory A or B, distance from machine while performing cleaning tasks and the fraction of sampling time spent on cleaning were significant determinants of total dust exposure. These fixed factors explained about 73% of the temporal variability in total dust exposure among cleaners.

The subset of total dust samples taken in parallel with respirable dust had a lower concentration (GM:  $102 \text{ mg/m}^3$ ) than the total set of total dust samples. The fractions of respirable-to-total dust for the cleaners and other production workers were 1.2% and 40.6%, respectively. The geometric mean alpha quartz concentration in the selected respirable dust samples from cleaners was  $0.02 \text{ mg/m}^3$ , reflecting a mean percentage quartz content in these samples of 0.55%. The geometric mean alpha quartz concentration for other workers was  $0.005 \text{ mg/m}^3$ , corresponding to a mean percentage quartz content of 0.78%. Five samples exceeded the TLV of  $0.025 \text{ mg/m}^3$  for crystalline silica (69). Only 7% of the production workers used respiratory protective devices.

---

### 4.3. Paper III

In this one year follow up study, chronic respiratory symptoms and changes in lung function were examined among cement factory workers (production workers and cleaners) and controls. The response rates of the interview and spirometry for the workers were 100 % and 71.1% in 2009 and 2010, respectively. The followed up and lost to follow up workers were not significantly different in smoking habits, height, weight, FEV<sub>1</sub>, FVC, and FEV<sub>1</sub>/FVC and use of respiratory protective devices at baseline. However, the followed up workers were younger, worked less years, and had less education than those who were lost to follow up, and these differences were significant among the cleaners.

Total geometric mean dust exposure among cleaners was 432 mg/m<sup>3</sup>. The fraction of samples exceeding the Threshold Limit Value (TLV) of 10 mg/m<sup>3</sup> for the cleaners varied from 84 to 97% in the four departments. The levels were considerably lower among the production workers (GM=8.2 mg/m<sup>3</sup>), but still 48% exceeded 10 mg/m<sup>3</sup>. The prevalence of all chronic respiratory symptoms among the cleaners and also among the production workers was significantly higher than among the control group. Forced Expiratory Volume in one second (FEV<sub>1</sub>) and Forced Expiratory Volume in one second/ Forced Vital Capacity (FEV<sub>1</sub>/FVC) were significantly reduced from 2009 to 2010 among the cleaners and production workers, but not among the controls. The one year reduction in FEV<sub>1</sub> among cleaners, production workers and controls was 99 ml, 92 ml and 32 ml, respectively. Cleaners who reported the chronic respiratory symptoms of cough and shortness of breath at baseline had reduced FEV<sub>1</sub> and FEV<sub>1</sub>/FVC in the follow-up period compared to those who did not have these symptoms.



## 5. Discussion

### 5.1. Methodological discussion

#### 5.1.1. Study design

The studies in this thesis have different designs, both cross-sectional (Paper I and II) and longitudinal (Paper III). Within the cross-sectional study in paper I, we also conducted a cross-shift study, a short follow-up of PEF measurements before and after shift. In cross-sectional studies, information is obtained at one time only (70, 71). Thus, conclusions on casual relationships cannot be drawn between cement dust exposure and respiratory health effects (71). Because of this weakness, we also conducted a longitudinal study (also called cohort or follow-up) which provide better information about the causation of disease (70). Cohort studies allow for the examination of multiple effects of a single exposure (71) and can be useful for investigating both chronic respiratory symptoms and lung function changes in relation to dust exposure (Paper III). The required time of follow-up may vary, depending on the outcome. Some diseases may occur long time after exposure. Information about past exposure can be collected at the time the cohort is established, and then participants are followed over a period of time to assess the occurrence of the outcome (70). Despite the short follow-up time in Paper III we have demonstrated reduced FEV<sub>1</sub> and FEV<sub>1</sub>/FVC among dust-exposed workers, but not among controls. We applied statistical methods and adjusted for confounders. The significant decrease in lung function during the follow-up period indicates a relationship between dust exposure and health outcome among cement production workers.

## 5.1.2. Validity

There are two types of validity; Internal and external.

Internal validity is the degree to which the results of an observation are correct for the particular group of people being studied. External validity or generalizability is the extent to which the results of a study apply to people not participating in the specific study (70, 71).

### 5.1.2.1. *Internal Validity*

#### *Participation rate*

The participation rates in our studies were high (Paper I and II). The reason for the high response rate is probably the close co-operation between the investigators and the factory management and workers. In a cohort study, loss of subjects during the study period will prevent direct measurements from the entire follow-up period, since the outcome of total study subjects is unknown (70). Our cohort study (Paper III) had 100% and 71% response rates in 2009 and 2010 respectively. However, the lost to follow-up (29%) and followed-up workers were not different in baseline characteristics regarding the health outcomes. However, the workers who were examined twice were younger than the lost to follow-up. Despite this, a deterioration of lung function was found.

#### *Selection bias*

Selection bias occurs when there is a systematic difference between the characteristics of the people selected for a study and the characteristics of those who are not. In occupational epidemiology, a very important selection bias is the healthy worker effect (70) which refers to overrepresentation of healthy persons at work compared to the general population. Also workers in exposed groups, for instance exposed to dust, might be more healthy than others, as sick workers quit for health reasons (selection out). Also workers have to be healthy to qualify for the job

(selection in) (72). Such biases will in many cases lead to an underestimation of work related disease in the work force. In Ethiopia, as a result of the high unemployment rate (73), workers might continue working even though they fall ill. Although we cannot exclude healthy worker effects also in Ethiopia, it is presumably of less importance than observed in high income countries.

Workers for dust sampling in Paper II and III were selected randomly which reduced the risk of selection bias in the assessment of dust exposure.

### *Information bias*

The major type of information bias is misclassification, which occurs whenever subjects are erroneously categorized with respect to either exposure or disease status. When misclassification is random or non-differential, the proportion of subjects erroneously classified in the study groups are approximately equal. When misclassification is non-random or differential, the proportion of subjects misclassified differs between the study groups (74). In the latter case the observed estimate of effect can be biased in the direction of producing either an overestimate or underestimate of the true association, depending on the particular situation. In our study, there is a possibility that the exposure and health outcome variables are misclassified differentially. This might have occurred because we used interview questionnaire for the respiratory symptoms. However, it is likely to be low because we attempted to reduce observer bias by using standard validated questionnaire in which the interviewer asked the same questions in exactly the same way to all participating workers.

### *Recall bias*

Recall bias arises when individuals with a particular adverse health outcome remember and report their previous exposure experience differently from those who are not similarly affected (70). In Paper I, we asked for acute respiratory symptoms immediately after the 8 hour work shift to avoid recall bias.

---

However, some recall bias might have been present in the interviews in Paper I and III since we asked for job history including previous jobs and previous illnesses. In Paper I we found that number of years of work in high-exposed sections was associated with cross-shift reduction in PEF.

### *Confounding*

Confounding occurs when the study population has another exposure which is associated both with the disease and the exposure being studied. A problem arises if this extraneous factor is unequally distributed between the exposure subgroups (70-72).

Smoking can be a confounder in the development of respiratory symptoms in the cement industry (54). Information on smoking was obtained in the interviews, and adjustments for smoking were performed in the analysis. In Paper I, the prevalence of smoking was 10 %, both among exposed and controls. Using multiple linear regression we were able to adjust for this variable. In Paper III, only two cleaners and one production workers were smokers, and the smoking factor was not considered in that study.

Age was significantly different between the exposed and control groups, and adjustments were performed in the analysis (Paper III).

Past illnesses such as pulmonary tuberculosis, asthma may potentiate respiratory effects and give chronic symptoms and signs (75). Such illnesses were asked for in the interview. No past respiratory illnesses were reported from exposed and control workers in Paper I. In paper III, two workers with asthma as a child and three workers with pulmonary TB were excluded from the analysis.

In Ethiopia the prevalence of pulmonary TB is high. In our study, no tests were performed on infectious diseases such as tuberculosis and HIV. However, the control groups were from the same place as the exposed workers, and we have no reason to

believe that there were differences in the prevalence of diseases in the exposed and the control group.

The presence of gases such as SO<sub>2</sub> and NO<sub>2</sub> are other potential confounders. However, our measurements of these gases did not show detectable levels, indicating very low exposure of these gases for the exposed groups.

Thus, the observed differences in respiratory health outcomes between the exposed and controls are assumed to result from differences in cement dust exposure.

#### 5.1.2.2. *External validity*

Since the locations of the factories were in the Eastern, Western and Northern part of the country, the study population was demographically diverse including workers from different parts of Ethiopia, thus presumably representative of Ethiopian people in an occupational setting. The age and employment distributions among the workers in our surveys were of similar magnitude to findings in other cement studies (33, 36, 38, 41, 54). Since the study included the major cement producing factories in Ethiopia, it is presumably representative of similar factories in Ethiopia. The work environment in the cement industries may vary due to different dust control strategies. The flow lines are partly open and there is lack of improved and efficient dust control mechanisms in the Ethiopian cement industry. Furthermore, cleaning is performed only by manual work, like sweeping with dry manual brooms and shoveling using shovels. Our results for cleaners are only representative of cement factories with this type of manual work. The dust levels for the production workers were in agreement with previous studies from other countries like, Tanzania and Malaysia (33, 41). Hence, the results of this study might be generalized to the working environment in similar plants with the same work routines in East Africa. Similar work environment might be present also in cement plants in other developing countries.

### **5.1.3. Questionnaire**

The validated BMRC questionnaire was used in Paper I and III. To be able to communicate with the study subjects in their own local languages, we translated the questionnaires from English to Amharic, with back translation according to the standard translation procedure. Since some of the workers could not read and write the questionnaire was used as an interview guide. Although it is not validated for Africa, the translated version used repeatedly in our study had good consistency.

In Paper III we used this validated questionnaire in the same manner with multiple questions to arrive at the particular chronic respiratory symptoms.

In addition we used another questionnaire with a 5-scale severity ranking of acute respiratory symptoms (Paper I), also translated to Amharic and used in an interview.

### **5.1.4. Exposure assessment**

The closed faced Millipore cassettes which were used in the present study may underestimate inhalable dust compared to the inhalable convention (76). Another possibility could have been to use the IOM-cassette, which is the most frequently used inhalable sampler. However, this IOM-cassette can easily be affected in physically harsh environment. Since the air inlet of this sampler is wide and open the filters might be broken, particularly when workers use pressurized air for cleaning dust from machines, which is the case in Ethiopian cement plants. Another alternative could have been to use the thoracic sampler. The thoracic sampler has been considered to sample the aerosol fraction of highest relevance regarding exposure to the bronchi, the site of hypothesized obstructive lung changes (45). However, at the time of the present study, no other studies in the cement industry had used thoracic samplers. It is of importance for the Ethiopian cement industry to compare exposure levels with cements factories in other countries and also to compare with international recommended limits. Such limit values are lacking for the thoracic fractions of dust. The closed faced Millipore cassettes have the advantage to protect the filter.

Furthermore, our results could be directly compared with previous studies that have mostly used this sampler (33).

The dust measurements were used for grouping of workers into production workers and cleaners as the contrast was high in the exposure level between these groups. This implies there were large differences in the mean dust exposure between the two groups. The exposure grouping (Paper II and III) was based on the high contrast in current total dust exposure between cleaners and production workers. However, the exposure of individual workers varies considerably from day to day within these groups because of varying conditions and tasks performed (Paper II and III), but the variability between the workers within these two groups are relatively small. Nevertheless the variability in exposure between the workers within the two groups may explain some of the variability in respiratory symptoms and lung function within the groups.

The fact that sampling was done within a relatively short time frames is one limitation of this study, since we could not investigate any long-term variability in dust exposure. This is because of economic constraints and also since the study must be performed in line with the allocated time frame for doctoral training at the University of Bergen.

Due to the excessive dust in the working environment for the cleaning workers, most of the filters were overloaded during the baseline measurements in 2009 (Paper III). When loose dust was detected on the sampling filter it was marked as overloaded by the laboratory, but both dust captured in the filter and the loose dust was measured. Because of this, the sampling time was reduced in 2010. However, we could not totally avoid the overloading. Hence, a more precise estimate of the sampling time could have been performed to reduce the uncertainty during the gravimetric analysis of the filters. However, the long term sampling made it possible to estimate the impact of the time spent on cleaning activities on personal exposure (Paper II).

Since there is no laboratory in Ethiopia specially designed for this purpose, the dust samples were transported to Norway. The transport disturbances including changes in humidity might have affected the accurate estimation of exposure levels in the laboratory. However, the filters were placed in climate-controlled room for at least 16 hours before weighing, and weighing was corrected with field blank filters.

The analyses of alpha-quartz in the dust samples is important because silicosis have been claimed to be the a risk for cement workers (37) In our study, the number of samples analyzed for alpha-quartz were limited due to funding.

#### **5.1.5. Lung function testing**

The lung function tests were performed in the field by only one person. Assessment of PEF, FEV<sub>1</sub>, FVC and ratio of FEV<sub>1</sub>/FVC are commonly used to measure ventilatory function in similar studies (77-79). The standard Mini-Wright flow meter can be considered to be reliable and widely validated (80), and hence we used it for measuring PEF (Paper I). A digital Spirare spirometer (SPS310) was used to measure ventilatory function indices (Paper III). We performed the measurements in accordance with the guidelines and recommendations of the ATS (66). It may be appropriate to compare lung function parameters to predicted values from a suitable reference population (67). However, we used actual measured values and did not compare to reference populations since predicted values from a representative Ethiopian population was not available.



## 5.2. Main discussion

### 5.2.1. Occupational cement dust exposure

#### *Dust levels*

Our survey demonstrated high total dust levels among cement production workers and excessive exposure of total dust among cement cleaners. In Paper I, the geometric mean total dust exposure among production workers were 38.6 mg/m<sup>3</sup> and 18.5 mg/m<sup>3</sup> in the crusher and packing respectively. Among these groups 77.5 % of the samples exceeded the TLV of 10 mg/m<sup>3</sup> for inhalable particles not otherwise specified (PNOS) (69). In Paper II, in both factories, cleaners had significantly higher geometric mean total dust exposure than other production workers 549 vs 3.9 mg/m<sup>3</sup> in Factory A and 153 vs 10.2 mg/m<sup>3</sup> in Factory B. Similarly in Paper III, we found excessive geometric mean total dust exposure among cleaners (432 mg/m<sup>3</sup>) compared to production workers (8.2 mg/m<sup>3</sup>). Total dust exposure among the production workers in our study is comparable to total dust exposure for cement production workers in Malaysia (GM: 8.52 mg/m<sup>3</sup>) (41) and Tanzania (GM: 10.6 mg/m<sup>3</sup>) (33), and higher than the levels found in the USA (AM: 7.5 mg/m<sup>3</sup>) (58) and in Norway (AM: 7.4 mg/m<sup>3</sup>) (40).

Among the production workers, we found lower geometric mean total dust exposure in the packing department compared to the total dust levels found in the packing department in Tanzania (21.3 mg/m<sup>3</sup>) (33). This is also the case in the crusher department where we found lower levels compared to the levels found in Tanzania 13.48 mg/m<sup>3</sup> (33) except in Paper I where our total dust levels in the crusher was three times higher. However, the levels we found in the kiln and raw mill departments for the production workers in Paper II and III were slightly higher compared to the Tanzanian study; 2.87 mg/m<sup>3</sup> and 1.85 mg/m<sup>3</sup> respectively (33).

---

The excessive exposures among the cleaners in the present study is probably due to open flow lines, leakages from machines, lack of enclosure, lack of maintenance, lack of general mechanical ventilation, lack of local exhaust ventilation from the crusher and packing machinery and inefficient natural ventilation in the work area.

We also found high respirable dust among cleaners and production workers. The fractions of respirable dust samples that exceeded the TLV of  $1 \text{ mg/m}^3$  for Portland cement dust (69) were 84.6% among cleaners and 80% among other workers, respectively.

The concentrations of alpha quartz in respirable dust were comparable to the levels in cement factories in Norway (range  $<0.01\text{-}0.06 \text{ mg/m}^3$ ) (40) and the United States (median:  $0.079 \text{ mg/m}^3$ ) (39). It is difficult to know to what extent this part of the dust can be related to the respiratory symptoms and lung function changes found in the present study.

### *Dust fraction*

In our study the fraction of respirable-to-total dust for the cleaners and other production workers was 1.2% and 40.6%, respectively. This indicates that in terms of mass, the coarser particles dominate in the cement factories. Mwaiselage et al. (33) reported that the concentration of respirable dust by mass was approximately 40% of the “total” dust in a Tanzanian cement factory, which is in agreement with the group consisting of production workers. This suggests that inhaled dust may settle along the whole respiratory tract from the upper to the lower airways. The low fraction of respirable to total dust for the cleaners in our study could be due to the resuspension of piled dust during cleaning tasks such as shoveling and loading wheelbarrows. This resuspension may produce a continuous supply of coarser dust to the breathing zone. Thus, for the cleaners, a considerably larger proportion of the dust by mass is expected to be deposited in the upper part of the airways than is the case for the other production workers.

### *Exposure Variability*

In both Paper I and II, the exposure variability is high in all production departments. The within worker variability is higher than the between worker variability both among cleaners and production workers. For the cleaners, this is mainly due to the variability from day to day in fraction of time spent on cleaning and on how close to the dust emitting machines they are cleaning. Generally, also the time spent on outdoor activities and the mobility among production workers have been reported to be associated with high day-to-day (within-worker) variability (29, 30), and this factor may also contribute to the high within-worker variability in our study.

#### **5.2.2. Dust exposure and acute respiratory health effects**

Acute effects of cement dust exposure on the respiratory system were studied by investigating the changes in PEF and the development of acute respiratory symptoms across a work shift (Paper I). The exposed group had significantly more acute respiratory symptoms than the controls. These effects are presumably associated with the high concentration of dust in the working environment and may be related to the basic reactions caused by the cement dust, which irritate the respiratory tract. Compared to the Tanzanian study (48), among dust exposed workers, we found higher prevalences of acute respiratory symptoms for shortness of breath (47 % vs 43 %) and stuffy nose (85 % vs 78 %). However, we found lower prevalences for cough (30 % vs 41 %), runny nose (25 % vs 39 %) and sneezing (45 % vs 61 %).

We also found that the percentage cross-shift decrease in PEF was significantly more pronounced among high exposed workers than among low exposed controls, thus confirming the results reported previously about acute effect of cement dust on the respiratory airways (43, 44, 48). Mwaiselage et al. (48) found a 14% percentage cross-shift decrease in PEF for a nonsmoker, working for about 11 years and exposed to 10.6 mg/m<sup>3</sup> of respirable dust. When assuming that the concentration of respirable dust by mass in our study was also approximately 40% of the "total" dust, our regression equation predicts that the percentage cross-shift decrease in PEF would be

---

9% for a nonsmoker exposed to 26.5 mg/m<sup>3</sup> "total" dust and with 11 years of work experience in high-exposure sections. In the multiple linear regression model, the number of years of employment in the crusher and packing sections were associated with an increased percentage of cross-shift decrease in PEF. This may be caused by increased sensitivity of the airways related to long-term cement dust exposure in general or by hypersensitivity to specific components such as the trace amounts of chromium present in the cement dust, and might be a sign of chronic negative health effects coexisting with acute effects.

### **5.2.3. Dust exposure and chronic respiratory health effects**

In our follow-up study, we found that the dust exposed workers had higher prevalence of chronic respiratory symptoms and reduced lung function than controls (Paper III).

In both 2009 and in 2010, cleaners and production workers had significantly more chronic respiratory symptoms than the controls. Even though the cleaners were younger, they had the highest prevalence of respiratory symptoms. These effects are probably associated with the high concentrations of dust in the working environment. The prevalence of respiratory symptoms in general is assumed to increase with age, (81) thus supporting our suggestion that there is an association between cement dust exposure and chronic respiratory symptoms as the symptoms were highest among the cleaners who were younger than the production workers. Our findings confirm results from previous cross-sectional studies reporting a higher prevalence of respiratory symptoms among exposed cement workers when compared with controls (37, 41, 43, 49, 50). Among the production workers, in the present study, the prevalence of cough with sputum, chest-tightness and shortness of breath were lower than found in Nigeria (89, 81 and 54 % respectively) (7). The prevalence of wheezing was comparable to a study in Iran (28 %) (37). However, the prevalences of cough, cough with sputum and shortness of breath in our study were higher than found in Taiwan, Malaysia, United Arab Emirates and Tanzania (49, 41, 50, 53) (Table 2).

Despite the short follow-up period of one year, we also found that FEV<sub>1</sub> and FEV<sub>1</sub>/FVC were significantly reduced from 2009 to 2010 among the cleaners and production workers but not among the controls. Five years of follow-up is recommended to more reliably estimate an individual's rate of FEV<sub>1</sub> decline since the variability of FEV<sub>1</sub> is high after a follow-up period of only one year. However, to identify excessive declines as soon as possible, annual measurements are preferable (82). Mwaeselage et al. (57) found a decline of 49.1 ml in FEV<sub>1</sub> and 23.1 ml in FVC annually for a cement worker who is 38 years old, a non-smoker, and 170 cm tall, exposed to a total cumulative dust level of 28.9 mg/m<sup>3</sup> year. The decline in FEV<sub>1</sub> in our present study is almost the double, and for the cleaners, the dust level was much higher than presented for production workers in Tanzania. Our finding indicates that long term exposure to cement dust may cause declines in FEV<sub>1</sub> and FVC as found also in previous studies (55, 63, 79, 83). Despite the excessive dust exposure among the cleaners, cleaners do not seem to have larger reductions in FEV<sub>1</sub> than production workers. This might be related to the considerably higher fraction of coarser dust among cleaners than among production workers. Thus, for the cleaners, a larger proportion of the dust by mass might be expected to deposit in the upper part of the airways, also above the bronchial region, than is the case for the other production workers. Hence, a relatively smaller fraction of dust may penetrate into the bronchial region of the cleaners than expected from the excessive total dust exposure. This might partly explain why the cleaners did not have more reduced lung function than the production workers although their dust exposure was extremely high. Another contributing factor for not finding any difference in FEV<sub>1</sub> reduction between these groups could be that the cleaners were younger than the production workers (32 vs 36 years).

Cleaners who reported chronic respiratory symptoms such as cough and shortness of breath at baseline had reduced FEV<sub>1</sub> and FEV<sub>1</sub>/FVC respectively, compared to those who did not report these symptoms. This finding was in agreement with Saric et al. (62) who found that in the group of healthy workers, the initial values of ventilatory indices were significantly higher than in workers with chronic bronchitics. Our

findings suggest that workers with respiratory symptoms may be prone to a reduction of lung function related to excessive dust exposure (62). The clinical significance of these findings is unknown to us. Longer periods of follow-up are needed to reveal possible development of diseases.

## **6. Study conclusions**

This study demonstrates increased prevalence of acute and chronic respiratory symptoms as well as reduced lung function among high dust exposed cement production workers and excessively dust exposed cleaners than among the less exposed controls.

The results support the hypothesis that dust exposure in the cement production industry may lead to respiratory symptoms and lung function changes.

## 7. Recommendations

Specific to cleaners and production workers:

Immediate actions are suggested for the highest exposed workers. They should be provided with efficient dust masks and receive training in how to use them.

Enclosure of open flow lines will help to reduce dust leakages from machines and this will also help to reduce the work load and the dust exposure.

The cleaning method should be changed from dry sweeping to vacuum cleaning. Powerful vacuum cleaners with adequate air filtration will reduce dust exposure.

There is a general need for regular workplace inspections and health surveillance programs in the factories to monitor activities and to identify workers with respiratory health problems as early as possible, and to implement other effective engineering and administrative control of the work environment.



## 8. References

1. Science Views.com. Available at: <http://www.scienceviews.com/geology/cement.html>. Accessed on 16/5/2011.
2. World business council for sustainable development. Towards a Sustainable Cement Industry. Batelle. 2002.
3. Bhatti, Javed I, Miller, MacGregor F, Kosmatka, Steven H. *Innovations in Portland Cement Manufacturing*, CD400, Portland Cement Association, Skokie, Illinois, U.S.A.,2004.
4. Ridi F, Fratini E, Baglioni P. Cement: A two thousand year old nano-colloid. *Journal of colloidal and interface science*. 2011;357:255-264.
5. Facts about John Smeaton: lime mortar, as discussed in cement (building material): History of cement. Available at: <http://www.britannica.com/facts/5/609153/John-Smeaton-as-discussed-in-cement-building-material>. Accessed on 4/5/2011.
6. Moe S A, Health hazards of cement dust. *Saudi Med J*. 2004;25:1153-1159.
7. Oleru UG. Pulmonary function and symptoms of Nigerian workers exposed to cement dust. *Environ Res*. 1984;33:379-385.
8. MCG. Juenger, VHR. Lamour, P J.M. Monteiro, EM. Gartner, GP. Denbeaux. Direct observation of cement hydration by soft X-ray transmission microscopy. *Journal of material science letters*.2003; 22:1335-1337.
9. H du Plessis, E P Kearsley, H Matjie. Effect of grinding time on the particle size distribution of gasification ash and Portland cement clinker. *Journal of the South African Institution of Civil Engineering*. 2007;49(4):28–34.
10. Civil Engineer: Educational and Industrial Resources. Available at: <http://civilengineer.webinfolist.com/material/cement/properties.htm> Accessed on 26/05/2011.
11. Glasser F.P. Fundamental aspects of cement solidification and Stabilization. *Journal of Hazardous Materials*.1997;52:151- 170.
12. Fairhurst S, Phillips A, Gillies C, Brown RH. Portland cement dust: criteria document for an occupational exposure limit. Health and Safety Executive, London 1977.
13. Arumi C, Olotuh AO. Making of strong and durable concrete. *Emirates Journal for Engineering Research* 2006;11(1):25-31.

- 
14. Natt Makul, Burachat Chatveera, Phadungsak Ratanadecho. Use of microwave energy for accelerated curing of concrete. *Songklanakarin J. Sci. Technol.* 2009;31(1):1-13.
  15. Integrated Pollution Prevention and Control (IPPC) Guidance for the Cement and Lime. Environment Agency. Almondsbury, Bristol.2001.
  16. Dietz A, Ramroth H, Urban T, Ahrens W, Becher H. Exposure to cement dust, related occupational groups and laryngeal cancer risk: results of a population-based case-control study. *Int J cancer.*2004;108:907-911.
  17. GC. Bye. Portland cement. Thomas Telford Publishing. Second Edition. London.1999.
  18. Ka"ante U, Zevenhoven R, Backman R, Hupa M. Cement manufacturing using alternative fuels and the advantages of process modeling. *Fuel Processing Technology.* 2004;85:293– 301.
  19. Yisehak Seboka, Getahun M, Yared Haile-Meskel Biomass energy for cement production: Opportunities in Ethiopia. United Nations Development Programme, New York, 10017, USA,2009.
  20. Afro news: Ethiopia lifts cement import ban" [Online] Available at <http://www.afrol.com/articles/29438> (Accessed April 5, 2011).
  21. Ethiopian Investment Agency. Investment opportunity profile for manufacturing of cement in Ethiopia.2008.
  22. Action plan of World Business Council for Sustainable Development, July 2002. ISBN: 2-240940-42-6, Stevenage, Hert-fordshire, England.
  23. Bauer M, Grabsch C, Gminski R et al. Cement-related particles interact with proinflammatory IL-8 chemokine from human primary oropharyngeal mucosa cells and human epithelial lung cancer cell line A549. *Environ Toxicol.* 2010 published online DOI 10,1002/tox.20643.
  24. Gardiner K and Harrington JM. Occupational Hygiene. 2005. Third edition, Blackwell publishing Inc., 350 Main Street, Malden, Massachusetts, USA.
  25. Maynard AD. Measurement of aerosol penetration through six personal thoracic samplers under calm air conditions *J. Aerosol Sci.*1999;30(9):1227-1242.
  26. Gorner P, Simon X, Wrobel R et al. Laboratory Study of Selected Personal Inhalable Aerosol Samplers. *Ann. Occup. Hyg.* 2010;54(2):165-187.
  27. Lidén G, Melin B, Lidblom A, Lindberg K, Norén JO. Personal sampling in parallel with open-face filter cassettes and IOM samplers for inhalable dust-

- implications for occupational exposure limits. *Appl Occup Environ Hyg.* 2000;15:263–76.
28. Kromhout H, Symanski E, Rappaport SM. Comprehensive evaluation of within and between-worker components of occupational exposure to chemical agents. *Ann Occup Hyg.* 1993;137(3):353-370.
  29. Kromhout H. Design of measurement strategies for workplace exposure. *Occup Environ Med.* 2002;59:349-354.
  30. Rappaport SM, Kromhout H, Symanski E. Variation in exposure between workers in homogenous exposure groups. *Am Ind Hyg Assoc J.* 1993;54:654-662.
  31. Peters S, Thomassen Y, Fechter-Rink E and Kromhout H: Personal Exposure to Inhalable Cement Dust among Construction Workers. *J. Environ. Monit.* 2009;11:174-180.
  32. Mulhausen JR, Damiano J. Analysis of variance for refining similar exposure groups. A strategy for assessing and managing occupational exposure. *Am Ind Hyg Assoc J.* 1998; 59:287-304.
  33. Mwaselage J, Bråtveit M, Moen B, Yost M. Variability in dust exposure in a cement factory in Tanzania. *Ann Occup Hyg.* 2005;49(6):511-9.
  34. Adak MD, Adak S, Purohit KM .Ambient air quality and health hazards near mini cement plants. *Pollution Research.* 2007;26(3):361-364.
  35. Dräger-Tubes & CMS Handbook: Soil, Water, and Air Investigations as well as Technical Gas Analysis. 15<sup>th</sup> Edition. Dräger Safety AG & Co. KGaA, Lubeck, 2008.
  36. Mengesha YA, Bekele A. Relative chronic effects of different occupational dusts on respiratory indices and health of workers in three Ethiopian factories. *Am J Ind Med.* 1996;34:373.
  37. Neghab M, Choobineh A. Work related respiratory symptoms and ventilatory disorders among employees of a cement industry in Shiraz, Iran. *J Occup Health.* 2007;49:273-278.
  38. Ballal S.G, Ahmed HO, Ali BA, Albar AA, Alhasan AY. Pulmonary effects of occupational exposure to Portland cement. *Int J Occup Environ Health.* 2004;10:272-277.
  39. Abrons HL, Petersen MR., Sanderson WT, Engelberg AL, Harber PH. Symptoms, ventilatory function, and environmental exposures in Portland cement workers. *Br J Ind Med.* 1988;45:368-375.

40. Fell AK, Thomassen TR, Kristenen P et al. Respiratory symptoms and ventilatory function in workers exposed to portland cement dust. *J Occup Environ Med.*2003;45(9):1008-1014.
41. Noor H, Yap CL, Zolkepli O, Faridah M. Effect of exposure to dust on lung function of cement factory workers. *Med J Malaysia.*2000;55:51-57.
42. Smailyte G, Kurtinaitis J, Andersen A. Mortality and cancer among Lithuanian cement producing workers. *Occup Environ Med.* 2004;61:529-534.
43. Mengesha YA, Bekele A. Effects of acute exposure to different occupational dusts on pulmonary function indices of factory workers in Ethiopia. *Afr. Newslett. Occup. Health. Safety.*1997;7:8-9.
44. Ali BA, Ballal SG, Albar AA, Ahmed HO. Postshift changes in pulmonary function in a cement factory in eastern Saudi Arabia. *Occup Med.*1998; 48(8): 519-522.
45. Nordby KC, Fell A, Notø H, Edward W, Skogstad M, Thomassen Y, Bergamaschi A, Kongerud J, Kjuus H. Exposure to thoracic dust, airway symptoms, and lung function in cement production workers. *ERJ Express.* 2011, doi:10.1183/09031936
46. Abou Taleb, A.N.M., Musaniger, AO. and Abdel moneim, R B. Health status of cement workers in the United Arab Emirates. *J. Roy. Soc. Health.* 1995; 2:378-383.
47. Rafnsson V, Gunnarsdottir H. and Kiilunen M. Risk of lung cancer among masons in Iceland. *Occup. Environ. Med.*1997;54:184-188.
48. Mwaiselage J, Moen B, Bråtveit M. Acute respiratory health effects among cement factory workers in Tanzania: an evaluation of a simple health surveillance tools. *Int. Arch. Occup. Environ. Health.* 2005;79:49-56.
49. Yang CY et al. Effects of occupational dust exposure on respiratory health of portland cement workers. *J Tox Environ Health.* 1996;49(6):581-588.
50. Al Neaimi YI, Gomes J, Lloyd O. Respiratory illnesses and ventilatory function among workers at a cement factory in a rapidly developing country. 2001;51:367-373.
51. Laraqui Hossini CH, Laraqui Hossini O, Rahhali AE, Tripodi D, Caubet A, Belamallem I, et al., Respiratory symptoms and ventilatory disorders among a group of cement workers in Morocco. *Rev Mal Respir.* 2002;19(2 ):183-9.
52. Alvear-Galindo, M.-G., I. Mendez-Ramirez, J.-A. Villegas-Rodriguez, R. Chapela-Mendoza, C.-A. Eslava-Campos and A.-C. Laurell. Risk Indicator of

- 
- Dust Exposure and Health Effects in Cement Plant Workers. *Occup Environ Med.* 1999;41(8):654-661.
53. Mwaiselage J, Bråtveit M, Moen B, Mashalla Y. Respiratory symptoms and chronic obstructive pulmonary disease among cement factory workers. *Scand J Work Environ Health.* 2005; 31:316-23.
  54. Abudhaise BA, Rabi AZ, Zwairy MA, Hader AF, Quaderi SE. Pulmonary manifestations in cement workers in Jordan. *Int J Occup Environ Health.* 1997;10:417-428.
  55. Alakija W, Iyawe VI, Jarikre LN et al. Ventilatory function of workers at Okpella cement factory in Nigeria. *West Afr J Med.* 1990;9(3):187-92.
  56. Merenu IA., Mojiminiyi FBO., Njoku CH., Ibrahim MTO. The Effect of Chronic Cement Dust Exposure on Lung Function of Cement Factory Workers in Sokoto, Nigeria. *African Journal of Biomedical Research.* Vol. 2007;10:139-143.
  57. Mwaiselage J, Bråtveit M, Moen B et al. Cement dust exposure and ventilatory function impairment: an exposure-response study. *J Occup Environ Med* 2004;46(7):658-67.
  58. Abrons HL, Petersen MR, Sanderson WT, Engelberg AL, Harber P. Chest radiography in Portland cement workers. *J Occup Environ Med.*1997;39(11):1047-54 .
  59. Meo SA. Chest radiological findings in portland cement mill workers. *Saudi Med J.* 2003;24(3):287-290.
  60. Yang CY, Huang CY, Chang IC, Lee CH, Tsari JT, Ko CY. Pulmonary function and respiratory symptoms of Portland cement workers in southern Taiwan. *Gaoxiong Yi Xue Ke Xue Za Zhi.* 1993; 9(4):186-92.
  61. Rasmussen FV, Borchenius L, Holstein B. Lung function and long-term exposure to cement dust. *Scan J Respir Dis.* 1977; 58(3): 252-264.
  62. Saric M, Kalacic I, Holetic A. Follow-up of ventilatory lung function in a group of cement workers. *Br J Ind Med* 1976;33:18-24.
  63. Siracusa A, Forcina A, Volpi R et al. An 11-year longitudinal study of the occupational dust exposure and lung function of polyvinyl chloride, cement and asbestos cement factory workers. *Scand J work Environ Health* 1988;14:181-188.
  64. British Medical Research Council (BMRC). Standardized questionnaire on respiratory symptoms. *Br Med J* 1960,2,1665.

- 
65. Wasserfallen JB, Gold K, Schulman KA, Baraniuk JN. Development and validation of a rhinoconjunctivitis and asthma symptom score for use as an outcome measure in clinical trials. *J Allergy Clin Immunol.*1977;100:16-22.
  66. American Thoracic Society: Standardization of spirometry, 1964 update. *Am J Resp Crit care Med* 1995;152(3):1107-1136.
  67. Quanjer PH, Lebowitz, MD, Gregg I, Miller MR, Pedersen OF. Peak expiratory flow: Conclusions and recommendations of a working party of the European Respiratory Society. *Eur Respir J.* 1997;24(Supp),2-8S.
  68. Rappaport S M., Kupper L L. Quantitative Exposure Assessment. Stephen Rappaport, El Cerrito, California, U.S.A. 2008.
  69. American Conference of Governmental Industrial Hygienists (ACGIH): *Threshold Limit Values for Chemical substances and Physical Agents and Biological Exposure Indices.* Cincinnati, Ohio:ACGIH, 2008.
  70. Beaglehole R, Bonita R, Kjellstrom T. Basic Epidemiology. World Health Organization. 2003.
  71. Charles H. Hennekens and Julie E. Buring. *Epidemiology in Medicine.* Philadelphia: Lippincott Williams & Wilkins.1987.
  72. Checkoway H, Pearce N, Crawford-Brown DJ. *Research Method in occupational epidemiology.* Oxford university press. New York. USA. 1989.
  73. Denu B, Tekeste A and Van der Deijl H. *Employment Strategy Papers: Characteristics and determinants of youth unemployment, underemployment and inadequate employment in Ethiopia.* Employment Policies Unit, Employment Strategy Department 2005.
  74. Rothman KJ, Greenland S, Lash TL. *Modern Epidemiology.* Philadelphia: Lippincott Williams & Wilkins. 2008.
  75. Baldacci S: Allergy markers in respiratory epidemiology. *Eur Respir J* 2001; 17(4):773.
  76. Vocht F, Huizer D, Prause M, Jakobsson K, Peplonska B, Straif K, Kromhout H. Field comparison of inhalable aerosol samplers applied in the European rubber manufacturing industry. *Int Arch Occup Environ Health.* 2006;79: 621–629.
  77. Moe SA, Azeem MA, Ghori MG, Sabhan MED MER. Lung function and surface electromyograph of intercostal muscles in cement mill workers. *Int J Occup Med Environ Health.* 2002;15(3):279-287.

78. American Thoracic Society (ATS) statement. Snowbird workshop on standardization of spirometry. *Am Rev Respir Dis.*1979;119:831-838.
79. ATS. Standardization of spirometry-1994 update. *Am J Respir Crit Care Med.* 152: 1107-1136. 1995.
80. Levin E, Gold M: The mini-Wright expiratory peak flow meter. *Can anaesth Soc J* 1981, 28(3), 285-287.
81. Eagan TML., Bakke PS., Eide GE, Gulsvic A. Incidence of asthma and respiratory symptoms by sex, age and smoking in a community study. *Eur Respir J* 2002, 19:599–605.
82. Hnizdo E, Glindmeyer HW, Petsonk EL: Workplace spirometry monitoring for respiratory disease prevention: a methods review. *Int J Tuberc Lung Dis* 2010;14:796-805.
83. Gomzi M, Stilinovic J and Cvar G. Alpha 1-Antritrpsin and lung function in cement workers. *Med. Lav.* 1989;80:301-306.