Chapter 20
Design of a Low-Cost Full-Face Mask for Stone Carvers

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1 Introduction

Stone quarrying is one of the major sources of livelihood for men in Daang village, Rajasthan. However, the silica traces present in the red sandstone being quarried there poses a major threat to the labourers by causing a respiratory ailment—'Silicosis'. Silicosis, currently, has no cure and is fatal [1]. Because of this, the average life expectancy of these workers is around 45–50 years.

The only solution is to prevent the inhalation of stone dust. Implementation of dust suppression techniques is not possible in this case since this is an unorganized sector. Major constraints include the availability of resources such as electricity and finance. The labourers are currently given disposable facemasks. According to the users, these are uncomfortable and restrictive. Also, due to cost constraints, the same masks are being used for much longer time than it was designed for. This causes more dust to be accumulated in the filters making it harder to breathe for the user.

Use of nanofilters, as opposed to the HEPA filters used in conventional face masks, is explored in this paper. Nanofilters are thousand times more porous than HEPA filters and hence have lower pressure drops [2]. For facial measurements, anthropometry data of Indian subcontinent men is used. Surface modelling using CREO was done according to the anthropometry data. The technology of 3D printing was used as a fabricating technique to test the dimensions and comfort of the developed face masks.

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2 Need Analysis

The problem of Silicosis is prevalent mostly in unorganized sectors [3]. It is observed that the employers of these sectors usually lack the will or motivation to provide a safe working environment for their labourers. It was observed that the masks provided to the labourers were disposable and needed frequent replacement, which was not taken care of by the employer.

Stone quarrying being an unorganized sector, there can be serious economic constraints, which have to be looked into. For example, disposable masks can cost around Rs. 300–500 [4] and last anywhere between 24 and 48 h depending on the usage conditions. Masks with replaceable filters are also available but are priced considerably higher at around Rs. 8000–10,000 [4]. It was also observed during the field visits that the labourers do not use the masks citing suffocation, unpleasant odour and low ventilation.

Hence, there exists a need to develop a low-cost mask, which lasts longer and with replaceable filters.

3 Methodology

It was observed that the existing HEPA filters require frequent maintenance and can be expensive, which means that these are not ideally suited for the situation. A new type of filters known as nanofilter was tried in this paper. Nanofilters are thousand times more porous than HEPA filters. Higher porosity reduces the pressure drop in the mask. This means that the user can breathe more freely.

To take into account, the user comfort, facial anthropometry was studied, and the facemask was dimensioned accordingly.

3.1 Field and Market Survey

A field visit was undertaken to Maakanpur quarry (see Fig. 1) in Daang village, Rajasthan to get a clear understanding of the current situation. Following observations were made during the visit.

- The quarry was in a remote location, and there were no provisions of electricity in the work area.
- Quarry workers used hand tools such as hammer and chisel to cut out the stones.
- There was an acute problem of water shortage, and hence the use of water suppression techniques was not feasible.
- P1 masks were provided by the government through the employers. This, being an unorganized sector, there was no clear communication between the employer and the government as to the exact number of workers employed by the employer.

Fig. 1 Working environment in a stone quarry at Daang Village

- Labourers found the mask to be bulky and restrictive. They preferred thinner masks, which would be more comfortable.

To come up with feasible solutions, literature survey [4, 5] and market surveys were also conducted. Few of the methods used are mentioned here.

Face Masks. These are commonly used in various areas where dust is an occupational hazard. Face masks are cheap and easily available. They have a low initial cost, however, requires frequent replacement (once in every 5–7 days [4]) and maintenance.

Wet Dust Suppression Techniques. This technique is mostly used in the outdoor working environment. Water jets and sprays are used to suppress dust in the working area. The water droplets trap the dust particles and hamper its flow in the environment. This technique requires an initial investment and consumes a large amount of water.

Dry Dust Suppression Techniques. This method is similar to the previous one but consumes lower amount of water. The spray nozzle atomizes the water droplets and delivers it as fog in the working environment. It creates about 10-μm fog droplet, thus making it more efficient in terms of water consumption. The initial investment required is higher than that of wet suppression techniques.

Vacuum Attachments. Tool attachments are used in certain cases, where the dust is collected at the source. Handheld power tools such as power saws, drills, etc., can be made dust free by using vacuum attachments. This, however, requires more power and cannot be used for manual tools.

Working Cabin. A more sophisticated technique where an isolated working environment is created by restricting the dust flow using vacuum pipes and dust screens.

Table 1 Comparison of commercial masks

Name	Scope	Drawback
 Medical Masks	Used in hospital environment, outpatients, sanitary uses, etc.	High respiratory resistance, Low particle interception
 P1 masks	Used as dust mask. Protects against low level of dust (80% particle entrapment)	Lower filtration capacity. Poor comfort. High resistance
 N 95 masks	Occupational mask, used in microbial entrapment as well. Removes at least 95% of airborne particles	Poor comfort, high respiratory resistance
 R 95 masks	Used in environment with industrial dust, organic gas, etc.	Poor comfort, high pressure drops. Only 8 h of service life
 P 95 masks	Used in environment with organic gases and fumes. These masks are strongly resistant to oil	Poor comfort, high respiratory resistance. Certified for up to 40 h of use

These require heavy investments and are mostly used in highly organized sectors such as assembly units, paint rooms, etc.

Taking into account, the economic constraints and working environment, face mask was still found to be the best alternative. A market survey was also conducted to study currently available face masks. Comparison of the commercially available masks is given in Table 1.

The masks are numbered as per the percentage of particles it can entrap. 95 means 95% entrapment. Masks numbered 99 and 100 are also available. The masks provided by the government were P1 masks. P1 refers to European Standard EN 143. According to the standards, P1-rated masks should filter at least 80% of the airborne particles.

3.2 *Nanofilters*

Instead of HEPA filters, it was decided to use nanofilters to design the masks. Nanofilters are made of specially woven fabric which is thousand times more porous than HEPA filters. Being more porous, these filters offer lower pressure drops thereby making it easier for the user to breathe. Moreover, the entrapment is higher than that of existing HEPA filters [2].

Fig. 2 Velcro stitched around a strip of nanofilter

For this project, nanofilters were procured from Nano Clean Global Pvt. Ltd., which develops nasal filters [2] that are used to combat outdoor pollution. Figure 2 shows the nano filter used in the prototype mask.

3.3 Facial Anthropometry and 3D Modelling

It was observed that the mask dimensions are not optimal for the given utility. A major reason for the discomfort was the lack of free space inside the mask. To address this issue, a facial anthropometry study was done. Various literature is available regarding the same [6–8]. Based on the demographics of the labourers working at the stone quarry, anthropometry data [6, 7] was referred to for men from India and Nepal. Critical dimensions to be considered for mask design included minimal frontal breadth, face width, face length, bigonial breadth, nose length, nose protrusion, nose breadth, nasal root breadth, interpupillary breadth, and head breadth [7].

Based on the anthropometric data, a face profile was developed using surface modelling. CREO was used to perform modelling operations. The support structures were later modelled onto the profile in the process of development. For optimum viewing of the user, a wide viewing angle of 135° was provided in the model [8]. Slots were included to fit a transparent panel onto the mask. This acted as eye protection for stone carvers (Fig. 3).

The CAD modelling was done in such a way that it could be easily manufactured using 3D printing. Several iterations were done before arriving at the final model. The dimensioning was done such that the anthropometric constraints were met and also there was space for ventilation. Holes and vents were provided in the frame so that the user does not feel suffocated.

Fig. 3 The 3D model of the final prototype

3.4 Prototyping

The 3D printing technique was used to develop a prototype face mask. The materials used to print the model were Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS). A blend of these two materials was used in prototyping. A polycarbonate sheet was used as a transparent panel, which acted as eye protection. The whole model was printed as blocks, which were assembled later by matching the male–female slots provided in the individual blocks.

Filters were then attached to the mask. Velcro strips were glued on to the inner surface of the mask to make it reusable. Velcro strips were also stitched to the filters. This made it easier to replace the filters when clogged. Filters were attached to cover all the vents in the mask. Adjustable fabric straps were fitted in the provided slots. These straps were fitted with paddings and cushions so that the user feels comfortable while working. The edges of the mask were sealed using foam cushions.

4 Results and Discussions

The whole mask was printed in about 19 h. It was later assembled and glued for stiffness. The mask was qualitatively tested for comfort and users felt that this was more comfortable than existing face masks. The prototyping cost was Rs. 5000, which is still lower than the cost of a commercially available full-face mask. Costs can be further reduced in mass production. It can be deduced that a low-cost full-face mask can be developed, which can cater to the needs of stone miners and stone quarry labourers. The maintenance of the mask is also relatively lower as compared to the existing commercial masks. It was found that a nano filter strip can last up to 24–48 h of usage depending on the dust levels. The cost of a nanofilter strip is about Rs. 10, which is very inexpensive as compared to HEPA filters which cost about Rs. 200 and last for about 24 h of usage.

5 Conclusions

These observations show that nanofilters are best suited for this purpose. Considering the economic constraints of an unorganized sector, it is highly improbable that the employer is motivated enough to replace expensive filters. Further, the exact implications of using a nanofilter mask can be understood after implementing the mask in the actual field.

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