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Original Research Article

Prevalence of metal fume fever and its association with working conditions and chronic respiratory disorders among metal factory workers in eastern India

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ABSTRACT

Background: Metal fume fever (MFF) constitutes a formidable occupational infirmity, arising from inhalation of ultrafine metallic particulates, pre-eminently zinc oxide, during metallurgical vocations. It's symptomatology, characterized by pyrexia, bronchospasm, and the recurrent "Monday morning" febrile paroxysm, conceals a sinister trajectory toward chronic respiratory decline.
Methods: A cross-sectional epidemiological inquiry was conducted among 181 metallurgical operatives in Liluah, West Bengal (July-December 2024). Participants, conscripted via multi-stage randomization, were interrogated using a validated questionnaire encompassing socio-demographic indices, occupational exposures, and respiratory morbidities. Analytical dissections employed ANOVA, chi-square, Z-tests, and Pearson correlations via SPSS v20, consecrating significance at $p \leq 0.05$.
Results: MFF prevalence attained an alarming 87.8%, with mean recurrence of 5.91±4.58 episodes annually. Nearly half (49.7%) harboured chronic respiratory disorders: COPD (24.3%), chronic bronchitis (17.7%), and asthma (7.7%). Robust associations emerged between MFF occurrence and sex ($\chi^2=62.242$, $p<0.001$), literacy ($\chi^2=50.752$, $p<0.001$), smoking ($\chi^2=65.615$, $p<0.001$), alcohol use, PPE compliance, ventilation, shift schedule, and primary metal exposure. Frequency of MFF episodes correlated near-perfectly with age ($r=0.911$), occupational tenure ($r=0.928$), daily working hours ($r=0.838$), cigarette consumption ($r=0.952$), and smoking duration ($r=0.973$).
Conclusions: Metal fume fever demonstrates an exceptionally high prevalence among metallurgical workers, acting as a sentinel for chronic respiratory morbidity. The strong correlations with occupational exposures and lifestyle factors underscore its preventable nature. Implementation of protective strategies and worker education is imperative to mitigate long-term pulmonary damage.

Keywords: Industrial epidemiology, Occupational toxicology, Preventive respiratory medicine, Pulmonary morbidity, Workplace hazard mitigation

INTRODUCTION

Metal fume fever is a disease most often associated with welders. Welding may cause pulmonary inflammation from the submicron particles of metal oxides in the fumes. Most often, the metal oxide is zinc oxide, but cadmium and manganese and their oxides are also present in some welding processes. Metal fume fever presents as a flu-like syndrome with fever, malaise, bronchospasm, and bi-weekly variations in severity. Symptoms are classically weakest on Sundays and strongest after returning to work on Mondays and Tuesdays.

Improvement occurs over the course of the work week, but re-ex-exposure after return to work results in a return of symptoms, such as fever, malaise, and wheezing. For this reason, it is sometimes called "Monday morning fever". The first reported cases were in the 1830s. The association between metal oxides with symptoms of fever, dyspnea, and muscle aches was proven when Lehmann exposed himself and four volunteers to gaseous products of the welding process, including zinc oxide.[1]

The Bureau of Labor Statistics reports that the syndrome of metal fume fever is seen most often in welders, cutters, brazers, and solderers. Welders use many different techniques. The most common is using electric currents to create heat, slightly melt metals, and bond them together. Arc welding produces currents to create intense heat, which melts metals and facilitates bonding. The process chosen depends on the metals to be bonded. Zinc is the most common metal involved in these bonding procedures.

"Cutters" use an ionized gas called plasma, also of intense heat, to trim metal objects to specific dimensions. Plasma cutters may be involved in dismantling large objects such as ships, railroad cars, and buildings. Solderers and brazers use a third metal to join two or more other metal objects. Solderers typically work with small metal pieces that must be positioned precisely, for example, transistors or computer chips. Brazers connect dissimilar metals through the agency of filler material, thereby producing strong joints between multiple metals. Brazers may also apply coatings to protect against corrosion and wear.

Exposure to metal fumes has caused recognized illness for about 200 years and has been known under several names such as Monday fever, brass founders' ague, welders' ague, smelter chills, and zinc shakes.[2] Exposure is from inhaling fumes during the welding process or cutting galvanized metal. Galvanization is a process by which a zinc coating is applied to steel. This process protects the steel from oxidation, corrosion, and weakening.

Interestingly, aerosolized zinc oxide powder does not produce the symptoms, whereas fresh zinc oxide does. The difference has been ascribed to the differential in the size of the particles.[3] Zinc oxide powder particles are much larger than freshly produced zinc oxide.[1] Ultrafine particles less than one micron in size drive much of the pathologic effects of metal fumes.[3,4] There may be a type 1 hypersensitivity that may manifest as an angioedema allergic reaction.[5] Pulmonary function testing may show marked bronchospasm.[6]

The most important aspect of the workup of these patients is to obtain an occupational history of the patient. Smoking, alcoholism, and drug use are standard parts of social history.[7] But how the patient spends the day, either with occupation or avocation, may play a particularly important role in raising the suspicion of the practitioner for the emergency practitioner, occupational physician, pulmonologist, or other health care provider. The fact that the patient works as a welder in the galvanization process is a common clue for diagnosing metal fume fever. Failure to engage in an occupational and hobby history may result in missing this diagnosis, and the patient may repeatedly expose themselves to unsafe conditions without a mask, adequate ventilation, and prolonged work hours.[8,9] Chemistry, coagulation parameters, and chest x-ray are all usually normal or unchanged from baseline. There may be a small degree of leukocytosis.[10]

The patient's C-reactive protein is elevated, but it is non-specific.[9] In general, testing is not indicated unless another process is strongly suspected. Zinc oxide (ZnO) exposure during welding increases the polymorphic nucleated white blood cells in the bronchial lavage fluid but is not associated with changes in bronchospasm or pulmonary function.[7] Occasionally in more severe cases, there may be pneumonitis or even acute respiratory distress syndrome (ARDS).[11]

METHODS

This observational epidemiological study was conducted using a cross-sectional survey design in Liluah, West Bengal, over a period of six months (July 2024 to December 2024). The study population comprised adult workers employed in metal factories dealing with zinc, chromium, iron, steel, nickel, copper, and manganese.

A multi-stage sampling technique was employed to select participants. In the first stage, a line listing of all factories using the specified metals in Liluah was obtained, and five factories were randomly selected. In the second stage, a line listing of workers from the selected factories was procured, and simple random sampling (without replacement) was used to achieve the desired sample size.

The sample size was calculated using Cochrane's formula, based on a prevalence of 39.2% for metal fume fever reported in a prior study. Considering an absolute error of 10%, a non-response rate of 10%, and a design effect of 1.25, the final minimum sample size was determined to be 126.

Data collection was carried out by visiting the selected factories every Monday. 181 participants were identified and interviewed using a pre-designed, pre-tested

structured questionnaire. Written informed consent was obtained from all participants prior to data collection. Workers absent on the day of data collection were excluded from the study. The questionnaire consisted of two parts: the first gathered socio-demographic data (e.g., age, sex, education, years in employment, work schedule, and substance use history), while the second focused on the incidence and frequency of metal fume fever, exposure to metals, and clinically diagnosed chronic respiratory disorders.

The data were compiled in MS Excel 2021 and analyzed using IBM SPSS software version 20. Statistical averages, dispersions, and proportions were calculated, and appropriate tests, such as ANOVA, chi-square, and Z tests, were performed to examine associations between socio-demographic factors, work-related variables, and respiratory health outcomes. A p value ≤0.05 was considered statistically significant.

RESULTS

The study encompassed 181 participants engaged in metal-related industrial occupations. The mean age of participants was 39.90±10.52 years, with an age range of 19 to 55 years, indicative of a predominantly middle-aged workforce exposed to occupational hazards over extended durations (Table 1).

A substantial male predominance was noted, with 78.5% of the participants being male (n=142) and the remaining 21.5% female (n=39). Educational attainment revealed a predominance of lower educational status, with 48.1% having completed only primary education and 26.0% being illiterate. Secondary education was achieved by 24.3%, while only 1.7% were graduates.

Participants had a mean duration of employment of 10.49±6.57 years, with 75.7% engaged in work for six days per week and the remaining 24.3% for five days. The average number of working hours per day was 9.54±1.66 hours, underscoring substantial occupational exposure durations (Table 1).

Concerning lifestyle factors, 60.2% were current smokers, while 12.2% were former smokers and 27.6% had never smoked. Among smokers, the mean daily cigarette consumption was 9.85±9.34, with a range extending up to 25 cigarettes per day. The mean duration of smoking was 11.87±10.81 years. Alcohol consumption was reported by 28.7% of the cohort.

Table 1: Sociodemographic profile of participants (n=181).

Characteristics	Category	N	%	Mean±SD	Range
Age (years)	—	—	—	39.90±10.52	19-55
Sex	Male	142	78.5	—	—
	Female	39	21.5	—	—
Educational attainment	Graduate	3	1.7	—	—
	Secondary	44	24.3	—	—
	Primary	87	48.1	—	—
	Illiterate	47	26.0	—	—
Years of employment	—	—	—	10.49±6.57	1–23
Days worked per week	5 days	44	24.3	—	—
	6 days	137	75.7	—	—
Hours worked per day	—	—	—	9.54±1.66	8–12
Smoking status	Never smoked	50	27.6	—	—
	Former smoker	22	12.2	—	—
	Current smoker	109	60.2	—	—
Cigarettes per day (smokers)	—	—	—	9.85±9.34	5–25
Smoking duration (years)	—	—	—	11.87±10.81	0–30
Alcohol use	Yes	52	28.7	—	—
	No	129	71.3	—	—

Occupational exposure characteristics

A critical evaluation of occupational exposure (Table 2) revealed substantial deficits in protective practices. Only 39.8% reported good adherence to PPE usage, whereas 49.7% admitted to poor compliance. Similarly, ventilation conditions were deemed poor in 49.7% of work environments, moderate in 22.7%, and good in only 27.6%, further amplifying the risk of airborne fume inhalation.

Primary metal exposure was predominantly to zinc (49.7%), followed by iron (25.4%), copper (21.0%), manganese (2.2%), and nickel (1.7%). Day shifts were performed by 74.6% of workers, while 25.4% were engaged in night shifts. Substance use beyond smoking

was prevalent, with 14.9% reporting daily use, 13.8% weekly use, and 71.3% abstaining.

Table 2: Occupational exposure profile (n=181).

Variables	Category	N	%
PPE usage	Good	72	39.8
	Moderate	19	10.5
	Poor	90	49.7
Ventilation quality	Good	50	27.6
	Moderate	41	22.7
	Poor	90	49.7
Primary metal exposure	Zinc	90	49.7
	Iron	46	25.4
	Copper	38	21.0
	Manganese	4	2.2
	Nickel	3	1.7
Shift type	Day	135	74.6
	Night	46	25.4
Substance-use pattern	None	129	71.3
	Weekly	25	13.8
	Daily	27	14.9

The prevalence of metal fume fever (MFF) in the study cohort was alarmingly high, with 87.8% (n=159) of participants reporting at least one episode in the preceding year (Table 3). The distribution of MFF episodes exhibited considerable variation, with a mean of 5.91±4.58 episodes per year and a maximum reported frequency of 12 episodes per year, indicative of chronic and recurrent exposure.

Among the 159 affected individuals: 15.7% reported a single episode, 13.8% reported two or nine episodes, 15.1% experienced ten episodes, 11.9% suffered twelve episodes annually.

Chronic respiratory disorders were reported in 49.7% of the participants, with 24.3% diagnosed with chronic obstructive pulmonary disease (COPD), 17.7% with chronic bronchitis, and 7.7% with asthma, highlighting the long-term sequelae of MFF and occupational exposure.

Extensive chi-square analyses revealed statistically significant associations between multiple sociodemographic, occupational, and lifestyle variables with the occurrence of MFF (Table 4).

Male workers exhibited a significantly higher prevalence of MFF (98.6%) compared to females (48.7%, $p<0.001$).

A gradient of risk was observed, with illiterates (93.6%) and primary educated workers (100%) having substantially higher MFF prevalence than graduates (33.3%, $p<0.001$).

All current and former smokers (100%) reported MFF, whereas only 56.0% of never-smokers were affected ($p<0.001$).

Universal affliction was observed among alcohol consumers (100%) compared to 82.9% among non-consumers ($p=0.001$).

Workers with poor or moderate PPE usage had 100% prevalence, while those with good PPE usage had significantly lower MFF rates (69.4%, $p<0.001$).

Table 3: Prevalence, distribution of MFF episodes, and associated chronic respiratory disorders.

Section	Category	Sub-category/episodes	N	%
A. MFF prevalence (n=181)	MFF status	≥1 MFF episode (past year)	159	87.8
	MFF status	No episodes	22	12.2
B. Distribution of MFF episodes (n=159)	Episodes per year	1 episode	25	15.7
	Episodes per year	2 episodes	22	13.8
	Episodes per year	3 episodes	19	12.0
	Episodes per year	4 episodes	3	1.9
	Episodes per year	5 episodes	0	0.0
	Episodes per year	6 episodes	0	0.0
	Episodes per year	7 episodes	0	0.0
	Episodes per year	8 episodes	3	1.9
	Episodes per year	9 episodes	22	13.8
	Episodes per year	10 episodes	24	15.1
	Episodes per year	11 episodes	22	13.8
	Episodes per year	12 episodes	19	11.9
C. Chronic respiratory disorders (n=181)	Respiratory status	None	91	50.3
	Respiratory disorder	COPD	44	24.3
	Respiratory disorder	Chronic bronchitis	32	17.7
	Respiratory disorder	Asthma	14	7.7

Table 4: Associations between variables and MFF occurrence.

Variables	Category	MFF n/N	% MFF	χ^2 (df)	P value
Sex	Female	19/39	48.7	62.242 (1)	< 0.001
	Male	140/142	98.6		
Education	Graduate	1/3	33.3	50.752 (3)	< 0.001
	Secondary	27/44	61.4		
	Primary	87/87	100.0		
	Illiterate	44/47	93.6		
Smoking status	Never smoked	28/50	56.0	65.615 (2)	< 0.001
	Former smoker	22/22	100.0		
	Current smoker	109/109	100.0		
Alcohol use	Yes	52/52	100.0	10.095 (1)	0.001
	No	107/129	82.9		
PPE usage	Good	50/72	69.4	37.914 (2)	< 0.001
	Moderate	19/19	100.0		
	Poor	90/90	100.0		
Ventilation quality	Good	28/50	56.0	65.615 (2)	< 0.001
	Moderate	41/41	100.0		
	Poor	90/90	100.0		
Shift type	Day	113/135	83.7	8.534 (1)	0.003
	Night	46/46	100.0		
Chronic respiratory disease	None	69/91	75.8	24.769 (3)	< 0.001
	Asthma	14/14	100.0		
	Chronic bronchitis	32/32	100.0		
	COPD	44/44	100.0		
Primary metal exposure	Zinc	89/90	98.9	87.210 (4)	< 0.001
	Iron	44/46	95.7		
	Copper	30/38	78.9		
	Manganese	1/4	25.0		
	Nickel	1/3	33.3		

Poor and moderate ventilation were associated with 100% MFF prevalence, while good ventilation reduced the prevalence to 56.0% ($p<0.001$).

Night shift workers were universally affected (100%) compared to 83.7% among day shift workers ($p=0.003$).

All participants with asthma, chronic bronchitis, or COPD were affected by MFF (100%), while 75.8% of those without respiratory diseases reported MFF ($p<0.001$).

Zinc exposure was associated with the highest MFF prevalence (98.9%), followed by iron (95.7%), copper (78.9%), manganese (25.0%), and nickel (33.3%, $p<0.001$).

Pearson correlation analysis demonstrated robust, statistically significant positive correlations between MFF episode frequency and key continuous exposure variables (Table 5).

These findings elucidate a compelling dose-response relationship, wherein prolonged occupational tenure, extended working hours, high smoking intensity, and advanced age are directly proportional to the cumulative burden of MFF.

Table 5: Pearson correlations: continuous variables versus number of MFF episodes.

Variables	Pearson r	P value
Age	0.911	<0.001
Years of employment	0.928	<0.001
Days worked per week	0.671	<0.001
Hours worked per day	0.838	<0.001
Cigarettes per day	0.952	<0.001
Smoking duration (years)	0.973	<0.001

The analyses reveal that MFF is not merely a stochastic occurrence but is intricately determined by a confluence of personal behaviours, occupational exposures, and environmental conditions. Factors such as inadequate PPE, poor ventilation, night shift work, zinc exposure, and deleterious lifestyle habits (smoking, alcohol) substantially amplify MFF risk. Moreover, increased duration and intensity of exposure, both occupational and behavioural, are positively correlated with the frequency and severity of

MFF episodes, reinforcing the chronicity and occupational health burden of this entity.

DISCUSSION

The present scholarly inquisition into the occupational malady christened "metal fume fever" (MFF), a morbid affliction oft shrouded beneath the veil of underreporting and industrial oversight, hath illuminated, with ineluctable clarity, the lamentable epidemiological burden borne by the industrious denizens of the metallurgical establishments of eastern India. It is with erudite trepidation and meticulous academic rigor that the investigators have delineated the insidious interplay betwixt occupational exposure, personal habits, and respiratory sequelae within this distinct cohort of 181 factory workers, whose daily commerce with the volatile exhalations of metals hath rendered them vulnerable to this antiquated yet persistent malady.

The prevalence of MFF observed in this study, an alarming 87.8%, constitutes a staggering epidemiological testament to the virulence of occupational exposures in this geographic locale, eclipsing many antecedent reports from Western climes, wherein prevalence rates have oscillated between 30% to 50%, contingent upon the specific metallurgical processes involved.[1,2,6] The overwhelming occurrence within this cohort is plausibly attributable to egregious deficiencies in protective interventions, suboptimal engineering controls, and pervasive socio-economic constraints that curtail risk mitigation.

An ineluctable correlation hath emerged between educational attainment and susceptibility to MFF ($p<0.001$). Intriguingly, the entirely unlettered (93.6%) and those of rudimentary primary education (100%) exhibited near-universal affliction, whilst their more erudite counterparts were comparatively spared (33.3% among graduates) (Table 4).[11] Such findings, though intuitively anticipated, underscore the iniquitous dissemination of occupational health literacy, wherein the learned possess both awareness and, perhaps, agency to advocate for safer practices.[4,7]

The gendered dissection of this malady reveals a disquieting yet predictable male predominance, with 78.5% of the workforce constituted by males, within whom a staggering 98.6% suffered MFF, contrasted against 48.7% of the comparatively fewer female counterparts ($p<0.001$).[11] The gender disparity likely reflects the physical demands and hierarchical employment dynamics within these metallurgical enterprises, wherein males are more frequently conscripted into high-exposure vocations such as welding, smelting, or plasma cutting.[3,13]

The deleterious synergism between tobacco consumption and MFF prevalence emerges with indubitable statistical and biological significance. Not a single current or former smoker within the study cohort was spared the throes of MFF- a portentous 100% prevalence, compared to 56% among never-smokers ($p<0.001$).[11] The mechanistic underpinnings of this association may reside in the chronic inflammatory milieu induced by tobacco combustion, wherein pulmonary epithelia are rendered susceptible to the noxious ingress of ultrafine metal particulates.[4,5,12]

Alcohol imbibition, another prevalent indulgence among 28.7% of participants, exhibited an equally unequivocal association with MFF ($p=0.001$), corroborating prior epidemiological assertions that systemic impairment of mucosal immunity and hepatic detoxification pathways exacerbates vulnerability to inhalational toxicants.[1,8]

The occupational milieu, as delineated through ventilation quality, PPE adherence, and shift pattern, emerges as an unequivocal crucible for MFF pathogenesis. Those consigned to poorly ventilated environments (constituting 49.7% of the cohort) and bereft of adequate personal protective equipment (PPE) (49.7% reporting poor PPE usage) were universally afflicted by MFF, in stark contrast to the comparatively shielded subgroups ($p<0.001$).[11]

Moreover, the nocturnal shift, endured by 25.4% of workers, bore an unmitigated 100% prevalence of MFF, ostensibly attributable to circadian disruption, heightened fatigue, and diminished supervisory vigilance during the twilight hours ($p=0.003$).[11] These findings echo the cautionary proclamations of Palmer et al, who, in their seminal treatise, chronicled the nocturnal exacerbation of occupational respiratory maladies.[14]

The preponderance of zinc exposure among 49.7% of participants, with a correspondingly near-universal affliction rate of 98.9%, corroborates the well-established pre-eminence of zinc oxide fumes in MFF pathogenesis.[1,2,9] Other metals, though implicated to varying degrees- iron (95.7% prevalence), copper (78.9%), manganese (25%), and nickel (33.3%)- reiterate the hierarchical culpability of metallic agents, with zinc occupying the apex of pathogenic potency.

The pathophysiological discourse surrounding zinc oxide fumes remains one of elegant simplicity and formidable consequence; the inhalation of freshly generated, ultrafine zinc particulates (<1 micron) initiates an acute, self-limited, yet debilitating inflammatory cascade within the pulmonary architecture, mediated by neutrophilic recruitment and cytokine storm, oft culminating in bronchospasm, systemic malaise, and in severe instances, pneumonitis or acute respiratory distress syndrome (ARDS).[1,5,9,19]

A most compelling corollary to this investigation resides within the linear correlations delineated between cumulative occupational exposure parameters and the frequency of MFF episodes. Pearson correlation coefficients reveal formidable associations between years of employment ($r=0.928$), smoking duration ($r=0.973$), daily cigarette consumption ($r=0.952$), hours worked per

day (r = 0.838), and MFF episode frequency ($p<0.001$ for all).[11] These correlations, of near-perfect magnitude, bespeak an unassailable dose-response relationship, wherein temporal accumulation of exposure inexorably amplifies morbidity risk.

The spectre of chronic respiratory disorders, afflicting 49.7% of participants, represents a lamentable progression from the ostensibly self-limited MFF towards enduring pulmonary debilitation. COPD (24.3%), chronic bronchitis (17.7%), and asthma (7.7%) were prevalent, with those afflicted demonstrating a 100% concurrence with MFF episodes, affirming the hypothesis that recurrent, subclinical pulmonary insults engender cumulative epithelial injury and irreversible airway remodelling.[2,6,10,15]

These findings align with longitudinal studies such as those by El-Zein et al, wherein MFF emerged not merely as an acute, self-resolving affliction, but as a harbinger of protracted bronchial hyper-responsiveness and airflow obstruction.[6]

Now, regarding the axiom of limitations, the present scholarly enterprise, though executed with scrupulous methodological diligence, is nonetheless circumscribed by certain epistemological fissures which must temper the interpretation of its findings. Foremost, the cross-sectional design, while adept at unveiling statistical associations of formidable magnitude, remains ontologically incapable of adjudicating causal hierarchies or temporal trajectories; thus, the inexorable metamorphosis of metal fume fever from an ostensibly ephemeral febrile perturbation to irrevocable chronic pulmonary degeneration is herein inferred rather than longitudinally demonstrated. Secondly, the reliance upon self-reported symptomatology and occupational exposures renders the dataset susceptible to recall distortion, under-reporting, or conversely exaggeration, each an artefact of human memory and socio-cultural constraints, thereby compromising the granularity of exposure ascertainment. Furthermore, the geographical circumscription of the study cohort to a single industrial cluster within Liluah, though pragmatic, inevitably curtails external validity, for it is plausible that variations in metallurgical practices, ventilation engineering, protective regimens, and socio-economic determinants across other industrial ecologies might engender divergent epidemiological profiles. The exclusion of advanced diagnostic modalities- spirometric quantification, high-resolution imaging, and biomarker profiling of oxidative stress and inflammatory cascade do constitute another lacuna, for it precluded the objective corroboration of respiratory compromise that might otherwise have transmuted subjective testimony into irrefutable pathophysiological evidence. Moreover, the statistical dissections, albeit rigorous, were constrained by sample size considerations, whereby certain subgroups (e.g., manganese- or nickel-exposed workers, female labourers) were underrepresented, diminishing the robustness of subgroup inferences. Finally, the absence of a longitudinal surveillance arm forestalls insight into the natural history, remission, or progression of MFF across temporal horizons, thereby leaving unanswered whether repeated insults inexorably culminate in chronic bronchitis, COPD, or insidious interstitial fibrosis. Collectively, these limitations invite caution in extrapolation, and simultaneously delineate fertile avenues for future research of a prospective, multicentric, and biomarker-integrated design.

CONCLUSION

In summation, this scholarly endeavour hath rendered manifest the alarming ubiquity and grievous ramifications of metal fume fever within the metallurgical workforce of eastern India, wherein nearly nine-tenths of labourers are enmeshed within the pernicious embrace of this occupational scourge. The inextricable associations betwixt low educational attainment, noxious personal habits, hazardous workplace environments, and the malevolent aerosols of zinc oxide and kindred metals, have been herein unveiled with irrefutable statistical and epidemiological clarity.

The data bequeathed by this investigation unambiguously evince that MFF is not a transient, self-resolving febrile malady, but rather, a veritable sentinel of impending chronic respiratory degeneration. The inexorable correlation betwixt exposure duration, intensity, and disease severity underscores the urgent necessity for systemic, structural, and behavioural interventions.

It is, therefore, incumbent upon occupational health custodians, factory proprietors, and public health agencies to orchestrate a tripartite stratagem encompassing:

Rigorous enforcement of protective measures

Mandatory provision and stringent supervision of PPE usage, alongside engineering controls such as improved ventilation, particularly during nocturnal shifts.

Worker education and behavioural modification

Comprehensive health literacy programmes addressing both occupational hazards and the synergistic dangers of smoking and alcohol consumption.

Periodic medical surveillance

Regular screening for early markers of pulmonary dysfunction, enabling pre-emptive intervention and mitigation of chronic respiratory disorders.

In fine, the metallurgical crucibles of eastern India must transcend their current state of neglect and emerge as exemplars of industrial hygiene, wherein the welfare of the labouring multitude is neither subordinate to profit nor obscured by ignorance.

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