Received: 26 May 2022 | Revised: 18 January 2023 | Accepted: 23 January 2023

DOI: 10.1002/ajim.23464

RESEARCH ARTICLE

AMERICAN JOURNAL OF INDUSTRIAL MEDICINE WILEY

Disparities in job characteristics by race and sex in a Southern aluminum smelting facility

Elizabeth S. McClure PhD[1,2] | Whitney R. Robinson PhD[1,2,3] | Pavithra Vasudevan PhD[4] | Mark R. Cullen MD[5] | Stephen W. Marshall PhD[1] | Elizabeth Noth PhD[6] | David Richardson PhD[1,7]

[1]Department of Epidemiology, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA

[2]Carolina Population Center, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA

[3]Department of Obstetrics and Gynecology, Duke University School of Medicine, Durham, North Carolina, USA

[4]Department of African and African Diaspora Studies/Center for Women's and Gender Studies, University of Texas, Austin, Texas, USA

[5]Center for Population Health Sciences Stanford, Stanford University, Stanford, California, USA

[6]Environmental Health Sciences Division, Berkeley Public Health University of California at Berkeley, Berkeley, California, USA

[7]Department of Environmental and Occupational Health, University of California at Irvine, Irvine, California, USA

Correspondence
Elizabeth S. McClure, MS, 2101C McGavran-Greenberg Hall, CB #7435, Chapel Hill, NC 27599, USA.
Email: emcclure@unc.edu

Abstract

Background: Former workers at a Southern aluminum smelting facility raised concerns that the most hazardous jobs were assigned to Black workers, but the role of workplace segregation had not been quantified or examined in the company town. Prior studies discuss race and gender disparities in working conditions, but few have documented them in the aluminum industry.

Methods: We obtained workers' company records for 1985–2007 and characterized four job metrics: prestige (sociologic rankings), worker-defined danger (worker assessments), annual wage (1985 dollars), and estimated total particulate matter (TPM) exposure (job exposure matrix). Characteristics of job at hire and trajectories were compared by race and sex using linear binomial models.

Results: Non-White males had the highest percentage of workers in low prestige and high danger jobs at hire and up to 20 years after. After 20 years tenure, 100% of White workers were in higher prestige and lower danger jobs. Most female workers, regardless of race, entered and remained in low-wage jobs, while 50% of all male workers maintained their initial higher-wage jobs. Non-White females had the highest prevalence of workers in low-wage jobs at hire and after 20 years—increasing from 63% (95% CI: 59–67) to 100% (95% CI: 78–100). All female workers were less likely to be in high TPM exposure jobs. Non-White males were most likely to be hired into high TPM exposure jobs, and this exposure prevalence increased as time accrued, while staying constant for other race–sex groups.

Conclusions: There is evidence of job segregation by race and sex in this cohort of aluminum smelting workers. Documentation of disparities in occupational hazards is important for informing health interventions and research.

KEYWORDS

aluminum, health disparities, occupational cohort, structural racism

1 | INTRODUCTION

Some seminal studies have documented disparities by race, ethnicity, and gender in occupational exposures,[1–3] and there is a growing body of literature on contemporary disparities,[4–9] but little research has been done to formally examine occupational characteristics and exposures by gender and race in manufacturing industries. Further, most manufacturing occupational cohort studies have focused on White male industrial workers, with little empirical analyses of exposures among women or non-White workers.[4] The purpose of this manuscript is to add to the occupational epidemiology literature describing differences in workplace exposure burden by documenting race and gender differences in cumulative manufacturing workplace exposures, informed by theory of labor inequities[7,10,11] and testimony of former workers.[12] In this analysis, we are interested in estimating the total effect of race and sex on disparities in job characteristics and exposures. Racial and gender disparities in job characteristics and exposures may arise through multiple pathways. Discrimination may occur at the worksite; and, discrimination may also occur outside the worksite and commence well before a person is hired into a job. These longer-term processes, which may include racial and gender differences in access to educational resources, also play a role in employment segregation and subsequent job characteristics and exposures.[10,11] Given our focus on the total effects of race and sex on job characteristics analyses do not adjust for education.

The study concerns an aluminum smelting plant which was established in 1913 and operated for most of the 20th century. It is located in the southeastern United States, and in this company town, the smelter was the major employer for the entirety of its time of operation.[13] Environmental justice literature documents that workers and fence line communities of color are disproportionately burdened by toxin and hazard exposure throughout the United States,[4,14–16] and at this facility, many employees have reported that the least desirable jobs in the plant were most frequently assigned to Black workers.[17] Over the years, community members have voiced concerns over workplace injuries and a perceived high incidence of cancer, and a mortality study of an earlier cohort of unionized workers indicated excess respiratory and bladder cancer mortality among pot room workers (the department where Black males contributed the majority of their worker years).[18] In interviews conducted by one of the authors (P. Vasudevan), former workers have also described segregation in both their residences and their workplace, including worse working conditions for Black employees. In this facility, many Black workers report having suffered from high exposure to hazards and harmful chemicals,[12] but this workplace segregation has not been quantitatively documented.

Aluminum smelting is an electrolytic process on alumina, which is refined from bauxite ore. The alumina is dissolved in carbon-lined steel pots filled with molten cryolite baths, and aluminum electrolytically separated using current from carbon anodes hanging above. The electric current maintains a temperature of 1760–1780°F.[19] Aluminum smelting generates a variety of airborne chemical contaminants including carcinogenic coal tar pitch volatiles (a measure of polycyclic aromatic hydrocarbons) and fluorides, which are potent respiratory irritants.[20]

Health disparities resulting from workplace segregation may arise from differential risk of hazard and toxic exposures,[4] differential wages and occupational prestige,[10,21–23] and differential access to preventive care.[24] Using information on aluminum workers employed at the plant between 1985 and 2007, we compared distributions by race and sex of census-based prestige rank, wage, worker-rated danger, and total particulate matter exposure categories to provide quantitative documentation in support of former workers' experiences.

2 | MATERIALS AND METHODS

2.1 | Study setting

The study site is an aluminum smelter in a southeastern US town. A company town, the site was established by the corporate owner of the smelter. Residences, churches, schools, and businesses were racially segregated, and a highway remains a physical barrier between two communities, with the east side being majority White and the west side largely Black.[25] The aluminum smelting facility, its landfills, and dumping sites are located in the west side of town.[26]

2.2 | Study population

This study uses deidentified data from the American Manufacturing Cohort (AMC), which includes workers from several aluminum manufacturing facilities and is maintained at the Stanford Center for Population Health Studies.[27] This study's population is a subset of the AMC which includes all individuals (both salaried and hourly) who were ever actively employed at the smelting facility of interest between 1985 and 2007.

For the purposes of the current analyses, two study populations are defined: (1) the entire study population of workers; and, (2) the subset of the worker population limited to incident hires, defined as only those workers with start dates on or after follow-up began on January 1, 1985.

2.3 | Explanatory variables of primary interest

The primary explanatory variables of interest in the current analysis are race and sex. Information on these variables was derived from human resources files that recorded demographic information including date of birth, race, and sex. To have adequate sample size in stratified populations by race and sex, we dichotomized the race variable (which was originally coded as a seven-level variable) as White versus non-White. Any worker who identified with one of the seven categories other than "White," including those who identified as more than one race, were included in the non-White binary category.

2.4 | Outcome variables of interest

Four metrics were used to characterize outcomes of interest. These were occupational prestige (based on sociologic rankings of prestige by job title[23,28]), occupational danger (based on former workers' assessments), annual wage (standardized to 1985 US dollar), and estimated total particulate matter exposure (in mg/m^3, based on a job exposure matrix[29]). Information on these outcomes is derived from two administrative sources—human resources and industrial hygiene records.[30] These data include job titles, annual wages, and start/end dates of jobs for all workers; all were updated at the time of each change in job. In addition to work history data, job exposure matrix-based estimates of exposure to total particulate matter were used from industrial hygiene data.

2.5 | Occupational prestige

Occupational titles for workers in the aluminum manufacturing industry were coded to a standardized census classification through the National Institute of Occupational Safety and Health (NIOSH) Industry and Occupation Computerized Coding System (NIOCCS) single record coding tool.[31] Prestige ranks, on a four-point scale from low to high based on scores from national sociology survey results, were assigned to 1990 census-coded occupations and crosswalk-linked to 1970 census codes.[23,28] Appendix Table A1 shows the mapping of job titles to prestige, danger, and total particulate matter exposure metrics. Some examples of high prestige job titles include "Plant Manager" and "Financial Manager." Examples of low prestige job titles include "Potliner" and "Pot Tender." Manufacturing jobs (in the pot room, furnace, anode, cathode, and other departments) in general are categorized as low prestige.

2.6 | Worker-defined job danger

A group of former workers from the smelting facility scored each job title based on their perception of its danger. There is precedent for using worker perspective to characterize job hazards in the aluminum smelting industry; for example, Friesen et al.[32] found good concordance between perceived and quantified exposure metrics, as well as conceptual validity, when using worker perspective to characterize less readily available measures of job danger. Seven former workers were given a list of every job title in the data set (N = 103) and ranked each on a scale of 1–4, with 1 being the least dangerous and 4 being the most. In discussions of dangers at work, former workers described physical hazards, heat, and toxin exposures.[12] All of these dangers were discussed for consideration before former workers ranked the jobs. Jobs with more than 2 discrepant rank levels (N = 36) were brought to the full group for review and consensus was reached for all job titles. Some example low-danger job titles include "Secretary" and "Accountant." Examples of high-danger job titles include "Potliner" and "Pot Servicer." Workers stated that overall, the most dangerous jobs are in the pot room.

2.7 | Annual wage

Annual wages were standardized to the 1985 dollar, using annual conversion factors from the National Bureau of Labor Statistics' Consumer Price Index.[33] Annual wages were obtained from human resources records.

2.8 | Particulate matter exposure

Estimated job-title-specific total particulate matter exposure was quantified using a previously developed job exposure matrix. The job exposure matrix provides an average plant, department, and job-specific total particulate matter exposure at the time of measurement, which was conducted by the department between 1985 and 2000.[29] Estimated exposure levels are based on industrial hygiene samplers worn by a random subset of workers intended to represent day-to-day total particulate matter exposures in each position at the facility. Workers' exposures varied depending on location and time spent in specific tasks. For example, pot room production workers are likely to have elevated exposure to coal tar pitch volatiles relative to maintenance workers who only enter pot rooms intermittently.[34] Administrative and management-style jobs, including "Secretary" and "Accountant," as well as salaried employees, that were considered by the facility's industrial hygienist as unlikely to experience particulate matter exposure in excess of 30% of the allowable limit more than 5% of the time did not have measurements made, and were assigned a "no exposure" category.[29] Those jobs with measurements were divided into three categories (low, moderate, and high) such that there were equal numbers of workers in each group. Examples of job titles with high total particulate matter exposure include "Baghouse Fume and Control" and "Pot Servicer." Salaried jobs were not always in low exposure departments. For example, a "pot room supervisor" is a salaried worker with relatively high total particulate matter exposure. However, their exposure would be categorized as "no exposure" in this analysis because their salaried status precluded inclusion in the job exposure matrix.

2.9 | Statistical analysis

The quantity we wish to estimate is the total effect of race and sex on the prevalence of job characteristics and exposures. We examined the association between race and sex and changes in each job characteristic with time since hire. We aimed, conditional on continued employment, to characterize job mobility, analogous to economic or class mobility often described in sociology literature.[28] Using linear binomial regression models (generalized linear models with an identity link and a binomial outcome[35]), we compared each race–sex group's average probability of being in a more desirable job (e.g., less dangerous or lower exposure), each year since hire using a race and year interaction term, across the four job characteristics, which were dichotomized for interpretability and sample size within race–sex strata. For the prestige characteristic, we assessed probability of being in a higher prestige job (any category but lowest prestige); for danger, the probability of being in a less dangerous job (any category but highest danger); for wage, we assessed probability of being in a job that was not low-wage (above the bottom quartile of 1985 dollar-standardized wages for the entire study population); and for exposures, the probability of being in a lower total particulate matter exposure job (any category but high exposure). Models were adjusted for an individual study-member fixed effect to control for any time-invariant worker characteristics and calendar year. Models were not adjusted for education. Education may be related to our outcomes of interest (job characteristics and exposures). However, we do not believe that education affects race; therefore, education is not considered a confounder of the associations of interest. We do believe that race may affect access to resources that influence educational attainment; and, because we believe education may be related to the job characteristics and exposures of interest, one path by which race may influence the outcomes of interest is via education (i.e., race→education→job). The current analysis does not involve mediation analyses (e.g., decomposing how much of the total effect of race and sex on the prevalence of job characteristics operates through education). Such mediation analyses would require additional longitudinal data and strong assumptions to yield valid estimates.[36] Model-based predicted probability curves and confidence bands for each race–sex group were plotted in each job characteristic. While the linear models are not constrained, we capped reported values for estimates and confidence intervals for probabilities at 0 and 1. In the text, probabilities are multiplied by 100 and reported as percentages.

To assess potential for healthy worker survivor bias, we conducted analyses restricted to incident hires, as has been previously done in analyses of manufacturing workers.[37] Sample characteristics were quantified as well as distributions of each job characteristic (based on first job at hire) stratified by race–sex group.

3 | RESULTS

Table 1 shows the study population characteristics as well as those in the subpopulation of incident hires. This full study population includes 1234 workers, and the incident hire subpopulation includes 534 workers. Of the full study population, 1077 (87%) were male and 917 (74%) were White. Consistent with the demographics of town residents, over 90% of workers identifying as non-White were Black or African American. Former workers report that the vast majority of non-White workers at the plant identified racially as Black,[12,18] so the small number (<10) of non-White workers in the study population are categorized as Black in analyses. The worker population was an average age of 28 years old at hire and 36 years at the start of follow-up (1985). The incident hires were slightly older on the date they were hired and were younger at the start of follow-up (1985) in comparison to the full cohort. The gender and racial composition of the two cohorts were similar. The cohort had minimal (<1%) missing demographic data.

Table 1 also shows the characteristics of time accrued by workers in the full cohort and those of the incident hire subpopulation. The full cohort accrued a total of 287,894 person-months of active work time. About half (49%) of the full cohort's person-time, compared with 63% incident hire person-time, was spent working in jobs classified as low prestige. In 1985 dollars, the average annual wage over the study period was $42,632 in the full cohort. While 21% of the person-months contributed by the full cohort was spent in jobs considered by former workers to be the most dangerous, 32% of the months contributed by the incident hires was spent in these jobs. Eleven percent of the full cohort person-time compared with 18% of the person-time in the incident hires was spent in the jobs with the highest total particulate matter exposure. Similar proportions of the person-time were missing (person-time spent in jobs that did not have wages documented or under job titles that could not be mapped onto a category in the three other job characteristics) in the full cohort and incident hire subpopulation.

Figure 1 shows job trajectories (over time since hire) by race and sex across each of the job characteristics examined, as predicted by the linear binomial regression models. The curves in the top left represent the prevalence of workers in each year since hire in a higher-prestige job. At hire, non-White males had the highest percentage of workers in low prestige jobs (92%), followed by White males (74%), then non-White females (66%), then White females (44%). Over time since hire, non-White males had the slowest transition into higher prestige jobs, with 52% remaining in low prestige jobs after 20 years since hire. After 15 years since hire, White females were entirely working in higher prestige jobs and White males reached 100% prevalence of higher prestige jobs by 19 years since hire. Linear binomial regression model estimates and confidence intervals represented in the figure are shown in Table 2.

The top right of Figure 1 shows race–sex group trajectories for worker-defined job danger. At hire, non-White males had the highest percentage of workers in the most dangerous jobs (50%), followed by non-White females (40%), then White males (28%), then White females (16%). White females and White males reached 100% prevalence of lower danger jobs by 15 years since hire, and non-White females reached 100% by 20 years since hire. However, 10% of non-White males were still in the most dangerous jobs after 20 years since hire.

The bottom left of Figure 1 shows the probability of being in a higher-wage job as time since hire accrues. At hire, non-White females had the highest percentage of workers in low-wage jobs (53%), followed by White females (56%), then non-White males and White males (both 50%). Over time since hire, all male workers

TABLE 1 Characteristics of workers at start of follow-up (1985, or date of hire if later) and person-months full cohort (workers = 1234, person-months = 287,894) and incident hire sub-cohort (workers = 534, person-months = 79,466) for workers in the aluminum smelting facility, 1985–2007.

Variable	Full cohort (*n* = 1234), *n* (%)	Incident hire subcohort (*n* = 534), *n* (%)
Sex[a]		
Female	156 (13)	75 (14)
Male	1077 (87)	459 (86)
Race[a]		
Non-White	316 (26)	169 (32)
White	917 (74)	365 (68)
	Mean, median (25th–75th percentile)	**Mean, median (25th–75th percentile)**
Age at start date[b]	31, 28 (23–36)	36, 35 (26–3)
Age at start of follow-up[a]	38, 36 (27–47)	26, 27 (17–36)
	Person-months = 287,894, *n* (%)	**Person-months = 79,466, *n* (%)**
Census-based prestige rank[c]		
High prestige	40,449 (14)	8708 (11)
Medium high prestige	21,385 (7)	3422 (4)
Medium low prestige	58,335 (20)	7249 (9)
Low prestige	141,533 (49)	49,694 (63)
Worker-rated danger rank[d]		
Least dangerous	64,368 (22)	18,108 (23)
Not very dangerous	61,344 (21)	11,028 (14)
Dangerous	86,027 (30)	23,559 (30)
Most dangerous	61,765 (21)	25,079 (32)
Total particulate matter exposure rank[e]		
No exposure	171,235 (69)	46,492 (59)
Low exposure	28,640 (10)	10,437 (13)
Moderate exposure	31,291 (11)	8569 (11)
High exposure	30,547 (11)	13,968 (18)
	Mean, median (25th–75th percentile)	**Mean, median (25th–75th percentile)**
Active person-time by worker (in years)[f]	20, 19 (10–26)	12, 14 (7–17)
Annual compensation (in 1985 dollars)[g]	42,632, 39,213 (27,916–50,200)	46,950, 42,354 (35,701–58,084)

[a] *n* = 1 missing in full cohort, no missing in incident hire subcohort.
[b] No missing.
[c] Nine percent missing in full cohort, 13% missing in incident hire subcohort.
[d] Five percent missing in full cohort, 2% missing in incident hire subcohort.
[e] No missing.
[f] No missing.
[g] One percent missing in full cohort, <1% missing in incident hire subcohort.

maintained a 50% prevalence in low-wage jobs. Female workers' prevalence of individuals in low-wage jobs increased as time since hire passed for both race groups but more quickly for non-White females. After 20 years since hire, all non-White female workers were in low-wage jobs.

The bottom right of Figure 1 shows the probability of being in a job with lower exposure to total particulate matter. Non-White males were most likely to be hired into a job with high exposure (24%), and as time accrued since hire, the prevalence of workers in lower exposure jobs decreased. While nearly all White females were hired

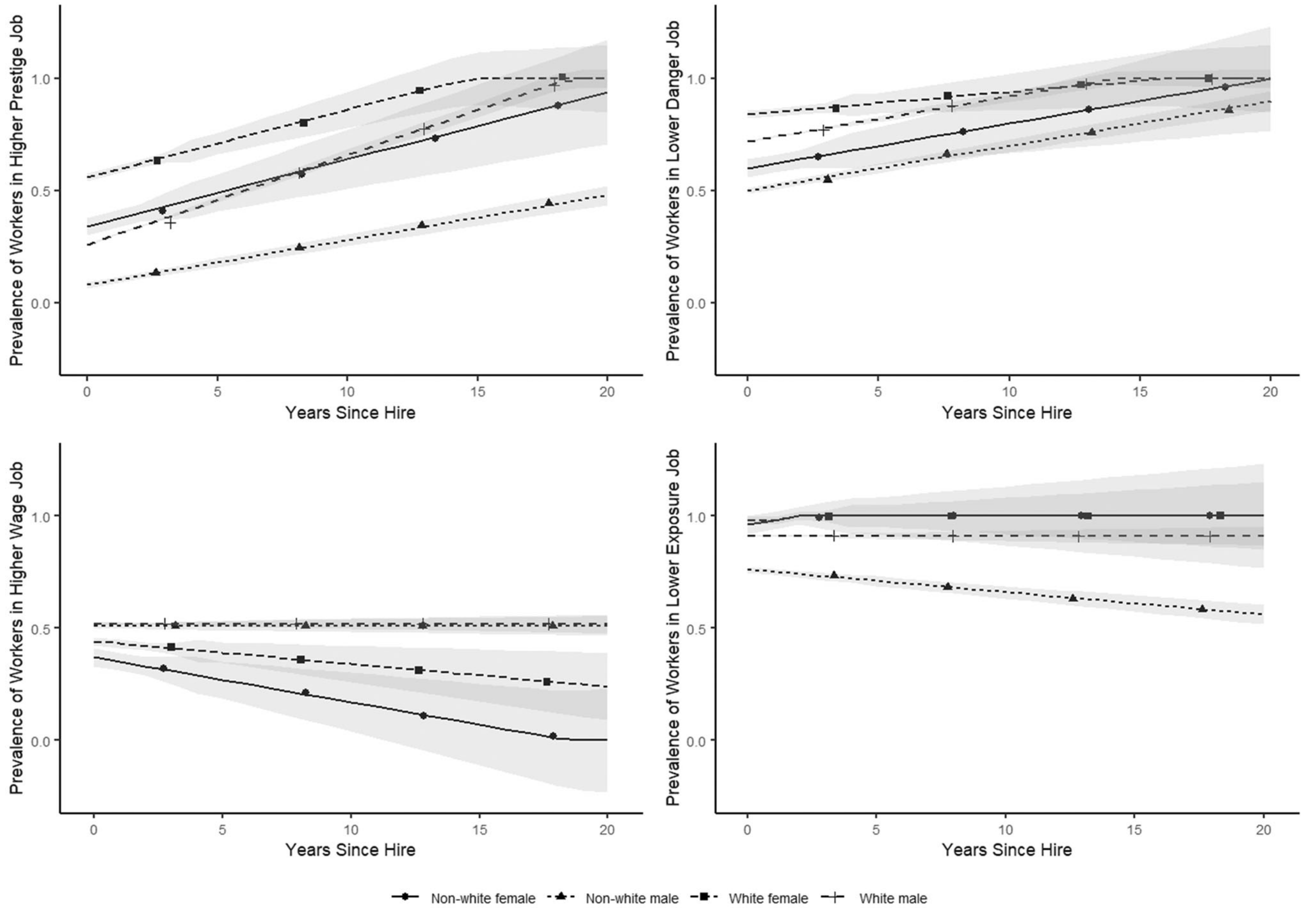

FIGURE 1 Linear binomial regression model predictions of prevalence in more desirable jobs over years since hire by race and sex in the full worker cohort, 1985–2007 (*N* = 1234). Linear binomial model predicted probability of being in a more desirable job each year since hire for each of the job characteristics. Stratified models were run for each race–sex group. Models are adjusted for individual study-member fixed effect. Plotted probabilities were capped at 0 and 1.

TABLE 2 Linear binomial regression model estimates of prevalence in more desirable jobs over years since hire by race and sex in the full worker cohort, 1985–2007 (*N* = 1234).

	Non-White female Estimate (95% CI)	Non-White male Estimate (95% CI)	White female Estimate (95% CI)	White male Estimate (95% CI)
Probability of being in higher prestige job				
Intercept	0.34 (0.30, 0.38)	0.08 (0.06, 0.09)	0.56 (0.54, 0.58)	0.26 (0.24, 0.25)
Slope	0.03 (0.01, 0.05)	0.02 (0.00, 0.04)	0.03 (0.01, 0.04)	0.04 (0.02, 0.06)
Probability of being in lower danger job				
Intercept	0.60 (0.56, 0.64)	0.50 (0.49, 0.51)	0.84 (0.82,0.87)	0.72 (0.71, 0.73)
Slope	0.02 (0.00, 0.05)	0.02 (0.01, 0.03)	0.01 (0.00, 0.04)	0.01 (0.00, 0.02)
Probability of being in higher-wage job				
Intercept	0.37 (0.33, 0.41)	0.51 (0.49, 0.52)	0.44 (0.42, 0.46)	0.52 (0.50, 0.53)
Slope	−0.02 (−0.05, 0.02)	−0.01 (−0.03, 0.02)	0.00 (−0.03, 0.03)	0.00 (−0.01, 0.01)
Probability of being in lower exposure job				
Intercept	0.96 (0.92, 1.00)	0.76 (0.74, 0.78)	0.98 (0.96, 1.00)	0.91 (0.90, 0.91)
Slope	0.02 (−0.01, 0.05)	−0.01 (−0.03, 0.02)	0.00 (−0.02, 0.02)	0.00 (−0.01, 0.01)

Note: Linear binomial models predicted probability of being in a more desirable job each year since hire for each of the job characteristics. Stratified models were run for each race–sex group. Models are adjusted for individual study-member fixed effect.

into low exposure jobs, and 100% were in low exposure jobs by 2 years since hire, a large proportion of non-White males were in high exposure jobs, with 44% in high exposure jobs by 20 years since hire.

The percentages of each race–sex group in the least desirable job characteristic category were similar between the incident hire and full cohorts. Non-White males had the greatest prevalence of lowest prestige (89%), most dangerous (64%), and highest total particulate matter exposure (26%) jobs at hire. Non-White females followed with the second highest prevalence of low prestige (75%) and high danger jobs (54%), but White males had the second highest prevalence of high total particulate matter exposure jobs (14%). Meanwhile, White males had lower prevalence of low prestige (67%) and high danger (34%) jobs at hire; and White females had the lowest prevalence of low prestige (62%) and high danger jobs (23%). Non-White females had the highest prevalence of low-wage jobs at hire (63%), followed by White females (54%), then non-White males (52%), with White males at the lowest prevalence (34%).

4 | DISCUSSION

This study examined differences in job characteristics (both at baseline and by trajectory) by race and sex among workers who were employed between 1985 and 2007 at an aluminum smelting facility in the southeastern United States. We found that non-White male workers were most likely to be hired into low prestige jobs and least likely to transition out of them. White male workers were the next most likely to be hired into low prestige jobs, but by 19 years since hire all were in a job with a higher prestige level. Non-White females were nearly as likely to be hired into low prestige jobs and less likely to move out of them, while White females were least likely to be hired into low prestige jobs. Non-White males and non-White females were the most likely to be hired into the most dangerous jobs, and White females and males moved out of the most dangerous jobs quickly and uniformly.

Additionally, there was a large sex difference in the prevalence of workers in low-wage jobs in this cohort, with male workers having higher percentages of workers in higher-wage jobs and the largest percentages of non-White females remaining in low-wage work as time accrued since hire. Females were less likely to be hired into jobs with high total particulate matter exposure than male workers, and non-White males had the highest prevalence of high exposure jobs. This reflects a pattern endorsed by former workers in which dirtier and more dangerous jobs received higher compensation.

These findings are consistent with former workers' narratives, which indicated segregated hiring and mobility in the plant. At meetings of retired plant employees in the study site, former workers report that nearly all workers in the pot room—the most dangerous and least desirable positions—were Black men, and Black women after gender integration. More White workers were hired into these positions starting in the late 1970s because of the mechanization of particular tasks associated with pot room production, specifically crust-breaking, but former workers report that White workers who were hired into the pot rooms were quickly moved into jobs in more desirable departments.[17] Quantitative documentation of race and gender disparities in work exposures at this site both supports the organizing of former workers and serves as one example of a common impact of workplace segregation. This adds to the literature describing which workforce populations carry the greatest exposure burden, a key mission of the occupational epidemiology field.

A strength of this study was that it focused on one southeastern US facility and was responsive to concerns expressed by former workers, whose input provided important context for interpretation of quantitative findings. However, our focus on a single facility inevitably limited the size of the study population. To ensure stability in estimated differences for some demographic groups, we were forced to dichotomize job characteristics and race categories. Additionally, because the data were collected for administrative purposes rather than for research, some of the variables are prone to misclassification. Notably, the race and sex variables may be self-reported or assigned by workers' supervisors. The "sex" variable in the human resources data may be an incomplete proxy for worker gender in this analysis, as the social constructions of gendered work roles may be more practically informative for workplace practices than does biologic sex.[38] Another limitation is the occupational prestige score that we used, which was developed in the late 1970s and neglects intergenerational and educational aspects of occupations.[39,40] We chose this scale instead of more modern interpretations of occupational prestige because this prestige scale adds an important dimension to the other job characteristics considered here and was developed during the time period of greatest relevance to former workers at this facility.

All prospective occupational cohort studies are affected by two potential sources of bias—survivorship into the cohort, and truncation of follow-up at termination. Because the aluminum smelter was in operation for many years before follow-up began in the form of digital collection of administrative records, we were concerned about the influence of the healthy worker survivor effect (sicker workers leave the workforce and healthier workers continue to accumulate exposure), which can attenuate study results.[41,42] We used sensitivity analyses[37] to assess the extent of potential HWSE through analyses using a subpopulation of incident hires, and found that the race and sex distributions of workers at hire were similar across the four characteristics between the incident hire and full cohorts, which suggests that our results are minimally affected by healthy worker survival effects. However, we note that these sensitivity tests do not fully address biases among early career workers, for whom health may be far less influential on job acquisition than social factors such as alternative job opportunities, discrimination in hiring, and so forth. Previous research in the AMC cohort shows that disability, absenteeism, and early termination vary by demographic factors including race, gender, and hourly/salaried wage scheduling.[43,44]

The reported analyses only include information about actively-employed workers; once a worker terminated employment at the plant their data were censored. The percentages of workers in the more desirable jobs 15–20 years since hire represent the members of each race–sex group still working at the plant. The trajectories we show demonstrate job mobility, conditional on staying employed at the plant. Former workers' reports indicate that it was difficult to find as high-paying work elsewhere as they obtained at the low prestige and high danger level of the pot room, and it is likely that White male workers had more opportunities to leave the plant for other jobs than non-White and female workers.[17] The trajectories of job characteristics might therefore appear more similar between race and gender groups as a consequence of such self-censorship bias.

Despite these limitations, this analysis provides quantitative support for community members' collective narratives of segregation and differential exposure burden among non-White workers in the aluminum smelting facility. These findings have been provided to community members in a report, which they may use to substantiate their concerns at public hearings and local government meetings. It additionally involved development, piloting, and demonstration of a novel, worker-generated scale for characterizing a salient job characteristic, perceived danger risk. No studies to date have assessed differences in aluminum smelting work exposures by race and gender. However, one study of coke oven steelworkers in the United States found that 69% of those working jobs with the highest levels of toxic exposure were non-White, while 9% of those working jobs with the lowest exposure levels were non-White.[45] This analysis begins to address this gap and also responds to calls in the literature to combine health disparities and work hazard research.[46–48]

4.1 | Conclusion

Given that high exposure jobs in the aluminum smelting industry have established associations with many diseases,[49–56] race and gender differences in job characteristics have implications for health equity. Based on our findings, job segregation and resulting race and sex differentials in experiences of occupational hazards may contribute to differences in mortality and morbidity by race and sex. Our findings suggest that job segregation may contribute to greater disease risk for non-White men and women, because we demonstrate increased exposures in these populations. This analysis may inform policy development by giving some indication of the potential benefits and limitations of equity-focused job assignment interventions and regulations.

AUTHOR CONTRIBUTIONS

Elizabeth S. McClure conceptualized and designed the study, drafted the initial manuscript, analyzed the data, created the tables and figures, assisted with the literature review synthesis, and approved the final manuscript as submitted. Whitney R. Robinson assisted in conceptual and analytic design, advised on the analytic strategy, provided commentary on the analysis, contributed to editing of the manuscript, and approved the final manuscript as submitted. Pavithra Vasudevan provided content to the analysis, assisted with the literature review, contributed to editing of the manuscript, and approved the final manuscript as submitted. Stephen W. Marshall advised on analytical strategy, contributed to editing of the manuscript, and approved the final manuscript as submitted. Elizabeth Noth contributed to the parent study data collection, assisted in exposure analyses, provided commentary on the analysis, contributed to editing of the manuscript, and approved the final manuscript as submitted. Mark R. Cullen contributed to the parent study design and data collection, advised on the analytic strategy, provided commentary on the analysis, contributed to editing of the manuscript, and approved the final manuscript as submitted. David Richardson provided overall supervision and guidance of the present analysis, assisted in conceptual and analytic design, advised on the analytic strategy, provided commentary on the analysis, contributed to editing of the manuscript, and approved the final manuscript as submitted.

ACKNOWLEDGMENTS

We acknowledge the generous funding sources that made this study possible: North Carolina Occupational Safety and Health Education and Research Center pilot project grant; Environmental Epidemiology training grant T32 ES007018; and the Carolina Population Center training grant T32 HD007168. We also acknowledge attendees of the Spirit of 1848 caucus sessions of the 2019 American Public Health Association Meeting, the Department of Epidemiology Environmental Epidemiology Seminar, and the Carolina Population Center Interdisciplinary Seminar for their thoughtful feedback in the early stages of this study.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICS STATEMENT

This research was approved by the University of North Carolina Institutional Review Board. Informed consent was not required for this review of deidentifed records.

REFERENCES

1. Mapel DW, Coultas DB, James DS, Hunt WC, Stidley CA, Gilliland FD. Ethnic differences in the prevalence of nonmalignant respiratory disease among uranium miners. *Am J Public Health*. 1997;87(5):833-838.
2. Mazumdar S, Redmond C, Sollecito W, Sussman N. An epidemiological study of exposure to coal tar pitch volatiles among coke oven workers. *J Air Pollut Control Assoc*. 1975;25(4):382-389.
3. Lloyd JW. Long-term mortality study of steelworkers V. Respiratory Cancer in coke plant workers. *J Occup Environ Med*. 1971;13(2):53-68.

4. Murray LR. Sick and tired of being sick and tired: scientific evidence, methods, and research implications for racial and ethnic disparities in occupational health. *Am J Public Health*. 2003;93(2):221-226.
5. Okechukwu CA, Souza K, Davis KD, de Castro AB. Discrimination, harassment, abuse, and bullying in the workplace: contribution of workplace injustice to occupational health disparities. *Am J Ind Med*. 2014;57(5):573-586.
6. Meyer JD. Race-based job discrimination, disparities in job control, and their joint effects on health. *Am J Ind Med*. 2014;57(5):587-595.
7. Krieger N, Chen JT, Waterman PD, et al. The inverse hazard law: blood pressure, sexual harassment, racial discrimination, workplace abuse and occupational exposures in US low-income black, white and Latino workers. *Soc Sci Med*. 2008;67(12):1970-1981.
8. Krieger N, Kaddour A, Koenen K, et al. Occupational, social, and relationship hazards and psychological distress among low-income workers: implications of the 'inverse hazard law'. *J Epidemiol Community Health*. 2011;65(3):260-272.
9. Chung-Bridges K, Muntaner C, Fleming LE, et al. Occupational segregation as a determinant of US worker health. *Am J Ind Med*. 2008;51(8):555-567.
10. Bergmann BR. Occupational segregation, wages and profits when employers discriminate by race or sex. *East Econ J*. 1974;1(2): 103-110.
11. Leeth JD, Ruser J. Safety segregation: the importance of gender, race, and ethnicity on workplace risk. *J Econ Inequal*. 2006;4(2): 123-152.
12. Vasudevan P. An intimate inventory of race and waste. *Antipode*. 2021;53:770-790. https://onlinelibrary.wiley.com/doi/pdf/10.1111/anti.12501?fbclid=IwAR2X2zGC4WaLsomS1ylC0ErELWjVTmsQGOhEjIGeG8wpRYC51L26LYY3MWg&)
13. Alcoa. Our History. 2016. Accessed April 15, 2017. http://www.alcoa.com/global/en/who-we-are/history/default.asp
14. Wing S. Whose epidemiology, whose health? *Int J Health Serv*. 1998;28(2):241-252.
15. Washington Office of Environmental Justice Drafted to the FNP of CELS. *The principles of environmental justice*. 1991.
16. Rector J. Environmental justice at work: the UAW, the war on cancer, and the right to equal protection from toxic hazards in postwar America. *J Am Hist*. 2014;101(2):480-502.
17. Concerned Citizens of West Badin. *Concerned citizens of West Badin in-person meetings*. Badin, NC: 2018.
18. McClure ES, Vasudevan P, DeBono N, Robinson WR, Marshall SW, Richardson D. Cancer and noncancer mortality among aluminum smelting workers in Badin, North Carolina. *Am J Ind Med*. 2020;63(9): 755-765.
19. Barham B, Bunker SG, O'Hearn D. *States, Firms, and Raw Materials: The World Economy and Ecology of Aluminum*. University of Wisconsin Press; 1994.
20. Friesen MC, Benke G, Del Monaco A, et al. Relationship between cardiopulmonary mortality and cancer risk and quantitative exposure to polycyclic aromatic hydrocarbons, fluorides, and dust in two prebake aluminum smelters. *Cancer Causes Control*. 2009;20: 905-916.
21. Christ SL, Fleming LE, Lee DJ, Muntaner C, Muennig PA, Caban-Martinez AJ. The effects of a psychosocial dimension of socioeconomic position on survival: occupational prestige and mortality among US working adults. *Sociol Health Illn*. 2012;34(7):1103-1117.
22. Himmelstein KEW, Venkataramani AS. Economic vulnerability among US female health care workers: potential impact of a $15-per-hour minimum wage. *Am J Public Health*. 2019;109(2):198-205.
23. Treiman DJ. A standard occupational prestige scale for use with historical data. *J Interdiscip Hist*. 1976;7(2):283-304.
24. Vidal L, LeBlanc WG, McCollister KE, et al. Cancer screening in US workers. *Am J Public Health*. 2009;99(1):59-65.
25. Franklin JH. The Rich Heritage of African Americans in North Carolina.North Carolina Division of Tourism, Film, and Sports Development. 2000.
26. North Carolina Environmental Justice Network. NCEJN congratulates the concerned citizens of West Badin community. 2013. Accessed February 21, 2017. https://ncejn.wordpress.com/2013/09/18/ncejn-congratulates-the-concerned-citizens-of-west-badin-community/
27. Elser H, Neophytou AM, Tribett E, et al. Cohort profile: the American manufacturing cohort (AMC) study. *Int J Epidemiol*. 2019;48:1412-1422.
28. Treiman DJ. *Occupational Prestige in Comparative Perspective*. Elsevier Inc.; 1977.
29. Noth EM, Dixon-Ernst C, Liu S, et al. Development of a job-exposure matrix for exposure to total and fine particulate matter in the aluminum industry. *J Exposure Sci Environ Epidemiol*. 2014;24(1): 89-99.
30. Pollack KM, Agnew J, Slade MD, et al. Use of employer administrative databases to identify systematic causes of injury in aluminum manufacturing. *Am J Ind Med*. 2007;50:676-686.
31. NIOSH. Occupation Computerized Coding System. 2018. Accessed March 1, 2019. https://www.cdc.gov/niosh/topics/coding/overview.html
32. Friesen MC, Demers PA, Spinelli JJ, et al. Validation of a semi-quantitative job exposure matrix at a Söderberg aluminum smelter. *Ann Occup Hyg*. 2003;47(6):477-484.
33. CPI Home. US Bureau of labor statistics. Accessed August 21, 2019. https://www.bls.gov/cpi/
34. Lavoué J, Gérin M, Côté J, Lapointe R. Mortality and cancer experience of quebec aluminum reduction plant workers. Part I: the reduction plants and coal tar pitch volatile (CTPV) exposure assessment. *J Occup Environ Med*. 2007;49(9): 997-1008.
35. McCullagh P, Nelder JA. *Generalized Linear Models*. 2nd ed. CRC Press; 1989:536.
36. Naimi AI, Kaufman JS, MacLehose RF. Mediation misgivings: ambiguous clinical and public health interpretations of natural direct and indirect effects. *Int J Epidemiol*. 2014;43(5):1656-1661.
37. Applebaum KM, Malloy EJ, Eisen EA. Reducing healthy worker survivor bias by restricting date of hire in a cohort study of Vermont granite workers. *Occup Environ Med*. 2007;64(10): 681-687.
38. Johnson JL, Greaves L, Repta R. Better science with sex and gender: facilitating the use of a sex and gender-based analysis in health research. *Int J Equity Health*. 2009;8(1):14.
39. Hauser RM, Warren JR. Socioeconomic indexes for occupations: a review, update, and critique. *Sociol Methodol*. 1997;27:177-298.
40. MacKinnon NJ, Langford T. The meaning of occupational prestige scores: a social psychological analysis and interpretation. *Sociol Q*. 1994;35(2):215-245.
41. Arrighi HM, Hertz-Picciotto I. Controlling the healthy worker survivor effect: an example of arsenic exposure and respiratory cancer. *Occup Environ Med*. 1996;53(7):455-462.
42. Checkoway H, Pearce N, Dement JM. Design and conduct of occupational epidemiology studies: II. Analysis of cohort data. *Am J Ind Med*. 1989;15(4):375-394.
43. Harrati A, Hepburn P, Meausoone V, Cullen MR. Characterizing long-term trajectories of work and disability leave: the role of occupational exposures, health, and personal demographics. *J Occup Environ Med*. 2019;61(11):936-943.
44. Harrati A, Modrek S, Cullen MR. Absenteeism, health, and disability in a large working cohort. Washington, DC: 2018.
45. Costantino JP, Redmond CK, Bearden A. Occupationally related cancer risk among coke oven workers: 30 years of follow-up. *J Occup Environ Med*. 1995;37(5):597-604.

46. Lipscomb HJ, Loomis D, McDonald MA, Argue RA, Wing S. A conceptual model of work and health disparities in the United States. *Int J Health Serv*. 2006;36(1):25-50.
47. Ahonen EQ, Fujishiro K, Cunningham T, Flynn M. Work as an inclusive part of population health inequities research and prevention. *Am J Public Health*. 2018;108(3):306-311.
48. Artazcoz L, Borrell C, Cortès I, et al. Occupational epidemiology and work related inequalities in health: a gender perspective for two complementary approaches to work and health research. *J Epidemiol Community Health*. 2007;61(Suppl 2):39-45.
49. Costello S, Neophytou AM, Brown DM, et al. Incident ischemic heart disease after long-term occupational exposure to fine particulate matter: accounting for 2 forms of survivor bias. *Am J Epidemiol*. 2016;183(9):861-868.
50. Neophytou AM, Noth EM, Liu S, et al. Ischemic heart disease incidence in relation to fine versus total particulate matter exposure in a U.S. aluminum industry cohort. *PLoS One*. 2016;11(6):e0156613.
51. Neophytou AM, Costello S, Brown DM, et al. Marginal structural models in occupational epidemiology: application in a study of ischemic heart disease incidence and $PM_{2.5}$ in the US aluminum industry. *Am J Epidemiol*. 2014;180(6):608-615.
52. Gibbs GW, Labrèche F. Cancer risks in aluminum reduction plant workers. *J Occup Environ Med*. 2014;56:S40-S59.
53. Gibbs GW, Labrèche F, Busque M-A, Duguay P. Mortality and cancer incidence in aluminum smelter workers. *J Occup Environ Med*. 2014;56(7):739-764.
54. Armstrong B, Tremblay CG, Cyr D, Theriault GP. Estimating the relationship between exposure to tar volatiles and the incidence of bladder cancer in aluminum smelter workers. *Scand J Work Environ Health*. 1986;12(5):486-493.
55. Björ O, Damber L, Edström C, Nilsson T. Long-term follow-up study of mortality and the incidence of cancer in a cohort of workers at a primary aluminum smelter in Sweden. *Scand J Work Environ Health*. 2008;34(6):463-470.
56. Rønneberg A, Haldorsen T, Romundstad P, Andersen A. Occupational exposure and cancer incidence among workers from an aluminum smelter in western Norway. *Scand J Work Environ Health*. 1999;25(3):207-214.

How to cite this article: McClure ES, Robinson WR, Vasudevan P, et al. Disparities in job characteristics by race and sex in a Southern aluminum smelting facility. *Am J Ind Med*. 2023;66:307-319. doi:10.1002/ajim.23464

APPENDIX A

TABLE A1 Job title categorizations for prestige, worker-defined danger, and total particulate matter exposure.

Metric	1	2	3	4
Prestige	Accountant Administrative Assistant/Secretary Area Supervisor-Mechanical Engineering Business Analyst Casting Technican Electrical Engineer Engineer Engineering Manager Industrial Hygiene IT Specialist Manager Mechanical Engineer Medical Metallurgical Engineer Metallurgical Technician Metallurgist Plant Manager	Area Supervisor-Laboratory Chemist Electrician Environmental Specialist Human Resources Laboratory Public Relations	Area Supervisor-Anode Area Supervisor-Casting Area Supervisor-Cathode Area Supervisor-Construction Area Supervisor-Electrode Area Supervisor-Engineering and Maintenance Area Supervisor-Field Maintenance Area Supervisor-Ingot Area Supervisor-Labor Area Supervisor-Machinist Area Supervisor-Potlining Area Supervisor-Potroom Area Supervisor-Smelting Maintenance Cathode Foreman Cathode Technician Central Maintenance Dam Maintenance Mechanic Electrical Maintenance Foreman Fume Control Technician Ingot Ingot Foreman Ingot Technician Labor Foreman Load Dispatcher Maintenance Foreman Mechanic	Anode Operator Anode Technician Bag House Repairer Bake Furnace Operator Brickmason Carpenter Caster Cathode Block Production Construction Construction Mechanic Crane Operator D C Operator Electrode Production Equipment Operator Filter Operator Furnace Operator Inspector Intern Janitor Lead Potliner Machinist Materials Processor Metal Furnace Operator Metal Processor Metal Trucker Millwright

AMERICAN JOURNAL OF INDUSTRIAL MEDICINE

TABLE A1 (Continued)

Metric	1	2	3	4
			Plant Clerk Pot Repair Foreman Potroom Foreman Rod-Chain Foreman Security Service Technician Shipping Foreman	Packer Loader Packer Puller Painter Pipefitter Pot Servicer Pot Tender Potline Technician Potliner Potlining Technician Potroom Potroom Technician Quanometer Operator Rod-Chain Handler Service Operator Smelting Operator Supply Attendant Tractor Loader Operator Truck Driver Welder
Worker-defined danger	Accountant Administrative Assistant/ Secretary Area Supervisor-Laboratory Brickmason Business Analyst Human Resources Intern IT Specialist Labor Foreman Laboratory Painter Plant Clerk Plant Manager Public Relations Security	Area Supervisor-Casting Area Supervisor-Construction Area Supervisor-Electrode Area Supervisor-Engineering and Maintenance Area Supervisor-Field Maintenance Area Supervisor-Ingot Area Supervisor-Labor Area Supervisor-Machinist Carpenter Chemist Construction Construction Mechanic Electrical Engineer Engineer Engineering Manager Industrial Hygiene Inspector Machinist Maintenance Foreman Manager Mechanical Engineer Medical Metallurgical Engineer Metallurgical Technician Metallurgist Shipping Foreman Supply Attendant Tractor Loader Operator Truck Driver Welder	Area Supervisor-Anode Area Supervisor-Cathode Area Supervisor-Mechanical Engineering Area Supervisor-Potlining Area Supervisor-Potroom Area Supervisor-Smelting Maintenance Caster Casting Technician Cathode Technician Central Maintenance Crane Operator D C Operator Dam Maintenance Mechanic Electrical Maintenance Foreman Electrician Environmental Specialist Equipment Operator Furnace Operator Ingot Ingot Foreman Ingot Technician Janitor Load Dispatcher Materials Processor Mechanic Metal Furnace Operator Metal Processor Metal Trucker Millwright Packer Loader Packer Puller Pipefitter Service Operator Service Technician	Anode Assembly Forman Anode Operator Anode Technician Bag House Repairer Bake Furnace Operator Cathode Block Production Cathode Foreman Cathode Technician Electrode Production Filter Operator Fume Control Technician Lead Potliner Pot Repair Foreman Pot Servicer Pot Servicer Pot Tender Pot Tender Pot Tender Potline Technician Potliner Potroom Potroom Foreman Potroom Technician Quanometer Operator Rod-Chain Foreman Rod-Chain Handler Smelting Operator
Total particulate matter exposure	Accountant	Machinist Crane Operator	Anode Operator Cathode Block Production	Anode Operator Anode Technician

(Continues)

TABLE A1 (Continued)

Metric	1	2	3	4
	Administrative Assistant/ Secretary	D C Operator	Crane Operator	Packer Puller
	Anode Assembly Forman	Metal Processor	Equipment Operator	Pot Servicer
	Area Supervisor-Anode		Furnace Operator	Pot Tender
	Area Supervisor-Casting		Lead Potliner	Service Operator
	Area Supervisor-Cathode		Potliner	
	Area Supervisor-Construction		Mechanic	
	Area Supervisor-Electrode		Supply Attendant	
	Area Supervisor-Engineering and Maintenance		Tractor Loader Operator	
	Area Supervisor-Field Maintenance		Truck Driver	
	Area Supervisor-Ingot			
	Area Supervisor-Labor			
	Area Supervisor-Laboratory			
	Area Supervisor-Machinist			
	Area Supervisor-Mechanical Engineering			
	Area Supervisor-Potlining			
	Area Supervisor-Potroom			
	Area Supervisor-Smelting Maintenance			
	Bag House Repairer			
	Bake Furnace Operator			
	Bake Furnace Repairer			
	Brickmason			
	Business Analyst			
	Carpenter			
	Caster			
	Casting Technican			
	Cathode Foreman			
	Cathode Technician			
	Central Maintenance			
	Chemist			
	Construction			
	Construction Mechanic			
	Dam Maintenance Mechanic			
	Electrical Engineer			
	Electrical Maintenance Foreman			
	Electrician			
	Electrode Production			
	Engineer			
	Engineering Manager			
	Environmental Specialist			
	Filter Operator			
	Fume Control Technician			
	Human Resources			
	Industrial Hygiene			
	Ingot			
	Ingot Foreman			
	Ingot Technician			
	Inspector			
	Intern			
	IT Specialist			
	Janitor			
	Labor Foreman			
	Laboratory			
	Load Dispatcher			
	Maintenance Foreman			

TABLE A1 (Continued)

Metric	1	2	3	4
	Manager Materials Processor Mechanical Engineer Medical Metal Furnace Operator Metal Trucker Metallurgical Engineer Metallurgical Technician Metallurgist Millwright Packer Loader Painter Pipefitter Plant Clerk Plant Manager Pot Repair Foreman Potline Technician Potlining Technician Potroom Potroom Foreman Potroom Technician Public Relations Quanometer Operator Rod-Chain Foreman Rod-Chain Handler Security Service Operator Service Technician Shipping Foreman Smelting Operator Welder			

Note: For all job characteristic metrics, 1 is best (high prestige, least dangerous, no exposure), and 4 is worst (low prestige, most dangerous, highest exposure).