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The Analysis of the Painting Work Clothes Clothing Comfort and Wearer Mobility Considering the Work Environment in the Machine and Shipbuilding Industries+

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Abstract

The purpose of the study was to analyze the work clothes' clothing comfort and wearer mobility of painting workers with the consideration of the work environment features in the machine and shipbuilding industries in South Korea. A questionnaire survey was conducted for the study, which consisted of questions on the clothing comfort and wearer mobility aspects of painting work clothes by clothes types and body parts. The work clothes' clothing comfort and wearer mobility levels were scaled in 5 points i.e. 1(: very tight/very uncomfortable) to 5(: very slack/very comfortable). The painting work environmental hazardous features were considered as high impact levels of workplace temperature, oxygen deficiency, organic solvent, toxic gas factors while metal fragment factor only impacts 'low' in the painting processes with the findings throughout this study. Since the painting work consisted of surface washing and the spray and touch-up painting processes, which was carried out in an outdoor work place, the painting work clothes should meet high performance of waterproofing from the painting material and air permeability specially in summer as well as thermal performance in winter. The subjects painting workers' assessment of the existing work clothes' clothing oppression was in the levels between 3 (i.e. moderate) and 4 (i.e. comfortable) in a range of 1 to 5 points. The existing painting work clothes' wearer mobility was evaluated 'very uncomfortable' in all work clothes parts, especially, armhole length, biacromial breadth, sleeve length of the jumper; and body rise, waist, hip, thigh and knee circumferences of the pants.

Key Words : painting work clothes clothing comfort, work clothes wearer mobility, painting work environments, work postures, painting work processes in the machine and shipbuilding industries

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I. Introduction

While some industries such as financial insurance, education, tourism, cultural contents and etc. have been creating high values without a smokestack, there have been others in relatively poor conditions in terms of work environment and tasks such as mining, construction and manufacturing in the heavy industries. In spite of the difficulties in work condition, such industries are playing an important role in the real economy, which is the foundation of the national competitiveness. Thus, all seem to be in agreement that it is one of the primary national issues to enhance the quality of work condition in such areas and to continue to make developments. Among heavy industries taking the lead of the national export, machine and shipbuilding industries are contributing a lot to the trade surplus in manufacturing businesses of Korea as of October, 2009. The export indexes of machine equipment and shipping except automobiles were 749.0 and 311.5 respectively with the standard index of 100 in 2005, which were the fifth and eleventh among 33 industries[1]. The manufacturing process in machine and shipbuilding industries, which utilize steel as the primary material, includes such operations as cutting, molding, assembly, welding, mounting, transferring, and inspection of the steel processed goods[2]. In particular, painting is one of the most important that prevents the external parts from being corroded or polluted during or after the processing and that maintains the outer appearance refined. Such painting work is essential in machine and shipbuilding industries in reflection of the demands in the business circles. However, most of the pigments used consist of a large amount of additives including organic compounds, and organic solvents contained in thinners for antifouling paints such as benzene, toluene, and xylene stimulate the worker's olfactory sense during the inhalation of the vapor, which may result in fatigue and dermatitis and dry skin upon pigmentation[3]. In addition, long-term or short-term exposure to such organic compounds may cause dyspnea, headache, suffocation, coma, anxiety, insomnia, prostration, chronic skin disease, and so forth. Thus, it is vital to prevent workers from being directly exposed to such organic solvents effectively. Painting work in machine and shipbuilding industries includes the combination of colors and thinner, pre-treatment to cleanse the steel plate before painting with the cleansing agent, whose major element is organic compounds, spray of high-concentrated paints over the large surface by means of a spray gun, and touch-up for partial coloring by means of a brush or roller on corners and inner parts of piping where spray cannot reach. organic solvents may result in serious diseases once they are absorbed in a body in proportion to the area and time of skin contact[4]. Thus, it is necessary for the worker to wear protective suits that cover the entire body and masks for safe respiration. In addition, workers of high-concentrated spray need a more strengthened protective method which prevents the air from coming inside and contains an air supplier.

In the preliminary study[5], the three major domestic industries - automobile, machine, and shipbuilding - were investigated, and the main processes were divided into 12 sections, each of which was classified again based on the impact indexes of environmental factors and motion factors on the involved workers. Based on the results, it turned out that painting work in

machine and shipbuilding industries involved such harm factors to the work environment as temperature, oxygen deficiency and exposure to harmful chemicals, metal particles and organic solvents. As the level of harms of each environmental factor was similarly high to each other, painting work was classified as a similar process in major heavy industries such as machine, automobile, and shipbuilding. In investigation of work clothes of painting workers in machine and shipbuilding industries in addition to harm factors of the working environment, the difficulties in air-conditioning for painting workers who mostly work outside need to be taken into consideration. For instance, required for work clothes are water repellent performance against harmful substances in colors, still air layer that prevents air permeability at lower temperature, sweat absorption at higher temperature, and sweat penetration. In addition to performances against harmful factors in painting work environment and work clothes, it is reported that motion-related elements of painting workers include a wide arrange of motions that involve movements, up down and sides, from the point of the human body in various working environments such as indoor and outdoor, outer walls of a structure, inner parts of piping, and so forth[6]. In painting work, insufficient motion-related performance of work clothes may result in serious damage to the worker's health and life in narrow space such as piping or block and on higher space. Thus, work clothes of painting workers require certain functional characteristics to prevent organic solvents from penetrating and to secure suitability to the workers possible motions.

This study, therefore, aimed to conduct specific evaluations on the painting work environments of each entity to which more than 130 painting workers belong in machine and shipbuilding industries located in the national industrial complex, Gyeongsangnamdo province, S. Korea. It also comparatively analyzed the clothing comfort and discomfort indexes of painting work clothes, collected painting work clothes actually used in machine and shipbuilding industries to examine the actual condition of the clothes in such areas as type, material, way of production, design, etc. The results are compared and investigated for each industry - machine and shipbuilding - to propose clothing performance and design that may improve the highlighted problems in current painting work clothes and provide with the fundamental material for the development of painting work clothes in machine and shipbuilding industries. As to the study results, presented is the solution to addressed problems based on the analysis of working environments where existing painting work clothes are used and of actual condition of workers' wearing, which aims to contribute to the performance improvement and development of new painting work clothes.

II. Methods

1. Subjects and Periods of Survey

To analyze harmful components in painting work environment of machine and shipbuilding industries, a major company from each of these two types of industry was selected for the study. The subject companies were located in the national industrial complex in the southern province of Gyeongsangnam-do, S. Korea and visited during the survey period from April to May, 2009. In addition, to define the current condition of wearing work clothes, and the

motion-related functionalities, a survey was conducted based on the individual in-depth interview with the process managers and the videos of operations were taken onsite. Among more than 130 workers in the selected two companies, a questionnaire survey was conducted from May to June, 2009. The basic work clothes, protective painting clothes, and safety gears that were actually used by the workers in the working environments were collected to explore its design and materials.

2. Questionnaires to Determine the Work Clothes Clothing Comfort and Wearer Mobility

The survey conducted among more than 130 workers in the painting processes of the machine and shipbuilding companies includes the following items: general information including age, height, weight, type of work, career, etc; duration and case of wearing work and protective clothes; clothing comfort evaluations including clothing pressure, wearer's mobility and physiological comfort when putting on and taking off; clothing discomfort evaluations for subjective assessment on each body section.

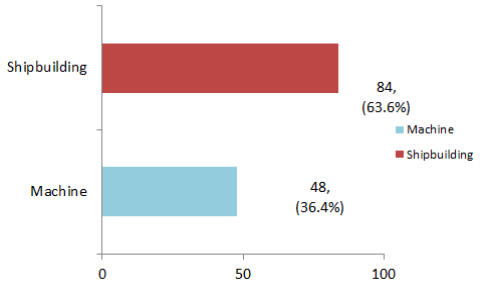
The questionnaire for this study includes the subjective sense assessment on the following aspects: pressure on chest, limbs, belly, and hips; physical mobility of sitting and standing; sense of putting on and taking off; physiological clothing comfort such as absorption, heat penetration, air permeability, liquid penetration, elasticity, and texture. To evaluate these aspects above, adopted was the 5-point Likert scale from very tight/very uncomfortable (point 1) to normal (point 3), and to very slack/very comfortable (point 5). Questions regarding clothing discomfort of each section of work clothes are multi-checkable. As to data analysis, carried out were Pearson's Chi-square test for verification of significant difference in averages of groups, and Duncan test for post-test examination.

As to the survey results, investigated was the clothing discomfort index of each body part as well as the work clothes clothing comfort, which was additionally considered with the impact index on work environment factors and motion factors of painting process in the machine and shipbuilding industries derived from the preliminary study.

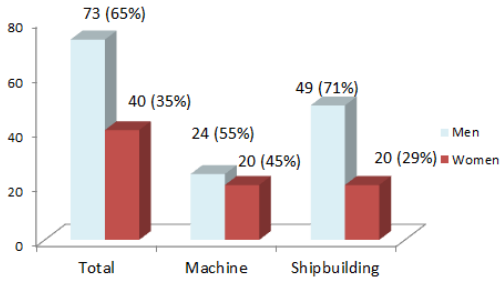
III. Results and Discussion

1. General Facts of the Subject Painting Workers

According to the analysis result of the personal information of more than 130 painting process workers in the machine and shipbuilding companies chosen for the survey, the ratio of workers in machine and shipbuilding was 36.4% to 63.6% <refer to Fig. 1>, the sex ratio of men and women was 55% to 45% in the case of machine painting work while that in the case of shipbuilding painting work 71% to 29%. In total, the sex ratio was 65% to 35%, which indicates that men were more than women <refer to Fig. 2 and Table 1>. As to the specific painting tasks in general, spray work was mostly handled by male workers while tasks in narrow space or brushing tasks such as touch-up were handled by female workers. Yet there was no difference between men and women regarding the types of painting work clothes wearing.



<Fig. 1> The ratio of painting workers in the machine and shipbuilding



<Fig. 2> The sex ratio of men and women painting workers

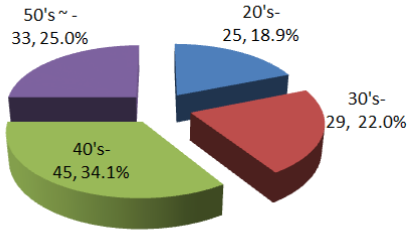
<Table 1> Demographic characteristics and general facts of painting workers

Item	Classification	Total(N=139)		Machine(N=48)		Shipbuilding(N=91)	
		N	Validity%	N	Validity%	N	Validity%
Sex	Male	73	64.6	24	54.5	49	71.0
	Female	40	35.4	20	45.5	20	29.0
	No response	26	–	4	–	22	–
	Total	113	100.0	44	100.0	69	100.0
Age	20~29yrs	25	18.9	1	2.1	24	28.2
	30~39yrs	29	22.0	7	14.9	22	25.9
	40~49yrs	45	34.1	19	40.4	26	30.6
	50~ yrs	33	25.0	20	42.6	13	15.3
	No response	7	–	1	–	6	–
	Total	132	100.0	47	100.0	85	100.0
Years of career	Less than 5yrs	66	50.0	22	46.8	44	52.4
	5~10yrs	34	25.8	18	38.3	16	19.0
	10~15yrs	20	15.2	5	10.6	15	17.9
	15~20yrs	7	5.3	1	2.1	6	7.1
	20~ yrs	5	3.8	2	2.1	3	3.6
	No response	7	–	0		7	
	Total	132	100.0	48	100.0	84	100.0
Daily worktime	Less than 8hrs	1	0.8	1	2.1	0	0.0
	8 or more hrs	131	99.2	47	97.9	84	100.0
	No response	7	–	0	–	7	–
	Total	132	100.0	48	100.0	84	100.0
Daily break-time	Less than 1hr	4	3.4	2	4.3	2	2.8
	1~2hrs	58	49.2	14	30.4	44	61.1
	2 or more hrs	56	47.4	30	65.2	26	36.1
	No response	21	–	2	–	19	–
	Total	118	100.0	46	100.0	72	100.0
Work days/Week	Less than 5 days	8	6.7	5	10.4	3	4.2
	5 or more days	111	93.3	43	89.6	68	95.8
	No response	20	–	0	–	20	–
	Total	119	100.0	48	100.0	71	100.0

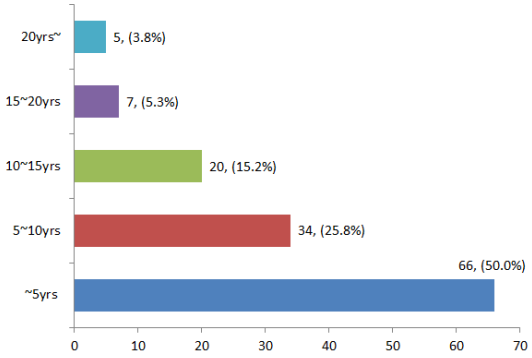
As to age distribution, the number of those in their 40's was 45(34.1%), 50's or more 33(25.0%), 30's 29(22.0%), and 20's 25(18.9%) respectively in the order<refer to Fig. 3>. Based on the result above, it turned out that painting workers in their 40's to 50's have a majority (59.1%) while the percentage of those in their 20's was the smallest.

In investigation of career year distribution of painting workers <refer to Fig. 4>, 50.0% of the subject responded that they had less than 5 years of career, which reflects that young ones do not prefer this type of work environment and leave the position shortly since it was hard and difficult. <Table 1> shows the demographic and general aspects of painting workers in machine and shipbuilding industries, their responds and percentages in the survey. As to career-related aspects, 46.8% and 52.4% of painting workers in machine and shipbuilding painting process had less than 5 years of career respectively, which was the majority of the subject. 38.3% of the machine industry painting workers had 5 to 10 years of career, 10.6% 10 to 15 years, 2.1% 15 to 20 years, and 2.1% more than 10 years, which shows that only 14.8% were experienced workers. This is the case of shipbuilding painting work too. 52.4% had less than 5 years of career, 19.0% 5 to 10 years, 17.9% 10 to 15 years, 7.1% 15 to 20 years, and 3.6% 20 years or more, which shows that only 28.6%, a relatively low percentage, were experienced workers.

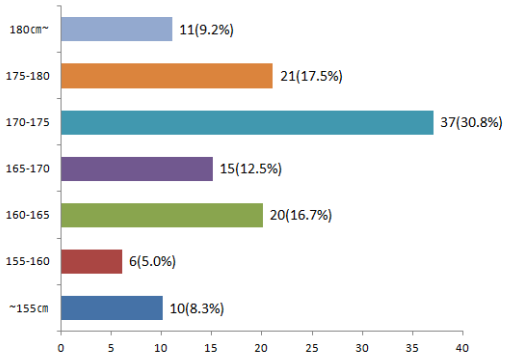
As to the height(unit: cm) distribution of painting workers in <Fig. 5>, the number of those in the range of 150 to 155 was 10(8.3%), 155 to 160, 6(5.0%), 160 to 165, 20(16.7%), 165 to 170, 15(12.5%), 170 to 175, 37(30.8%), 175 to 180, 21(17.5%), and 180 to 185, 11(9.2%) respectively. The highest percentage was workers in the range of 170 to 175, and that of those in the range of 175 to 180 was the next. These two held 40.3%. As to the weight(Unit: Kg) distribution, the number of those in the range of less than 55Kg was 20(17.4%), 55 to 60Kg, 18(15.7%), 60 to 65Kg, 28(24.3%), 65 to 70Kg, 18(15.7%), 70 to 75Kg, 14(12.2%), 75 to 80Kg, 9(7.8%), 80 to 85Kg, 4(3.5%), and more than 85Kg, 4(3.5%) respectively <refer to Fig. 6>.



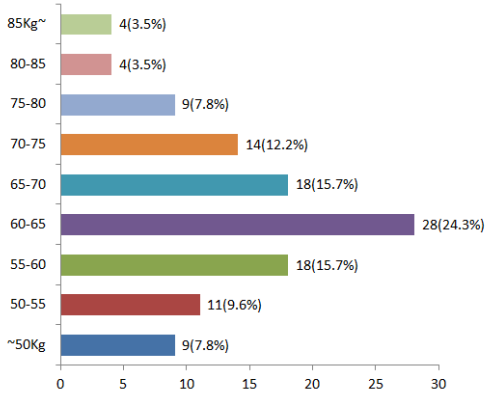
<Fig. 3> Age distribution of subject workers



<Fig. 4> Career year distribution of subject workers



<Fig. 5> Height distribution of subject workers



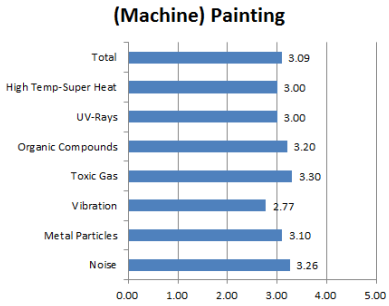
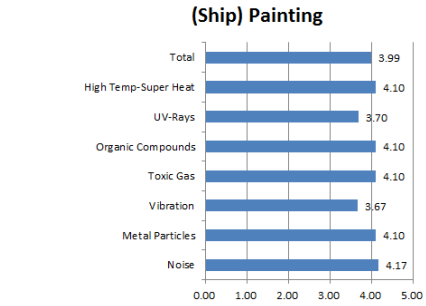
<Fig. 6> Weight distribution of subject workers

2. Characteristics of the Painting Work Environments

<Table 2> shows the photographs of the painting workers in the selected machine and shipbuilding companies through the survey and it explains the characteristics of the painting process and condition of work clothes wearing among the workers. In the machine industry painting process, paints with additive made from a large amount of organic compounds for the painting that prevents corrosion and pollution on the surface of processed goods after the molding and welding of steel. Thinners added to the paints include organic compounds such as benzene, toluene, xylene, and so forth. Thus, the use of organic compounds and volatile harmful gas is one of the major dangers in painting process, which may cause acute or chronic diseases due to skin pigmentation and inhalation. The combination of paints and thinners for the painting process, pre-treatment for cleaning the steel plate before painting work by means of cleansing agents including organic compounds, spray work that sprays highly concentrated paints over the large area by means of a spray gun, and touch-up that partially paints corners or inside of piping hard to spray on by means of a brush or roller are some of the processes which are done close to places of other processes. In addition to such organic compounds and harmful gasses, toxic fume, high temperature and harmful lights are likely to be exposed to workers. Harmful factors during painting work include organic solvents, toxic gas, vibration, metal particle, noise, high temperature and superheat, oxygen deficiency, and so forth. Painting workers in machine and shipbuilding industries are likely to work either indoor or outside, and even work in sealed areas such as external blocks of assembled machines and ships.

As to working motions, it was observed that they took difficult motions and positions in a high or narrow space depending on the formation of the structure. As a consequence, a survey was conducted among painting workers in machine and shipbuilding industries on the measure of risks regarding harmful factors in work environments. The results include the

<Table 2> Characteristics of painting process work environments and work clothes including protective gears in the machine and shipbuilding industries

Industry	Machine	Shipbuilding
Work Onsite		
Character-istics of Work Environ-ment	 Average index of risks of work environment factors required attention(3.09); specifically, toxic gas(3.30), noise(3.26), organic solvent(3.20), metal particle(3.10), hazardous light(3.00), high temp-superheat(3.00) required attention.	 Work environment factors of high risks; average index of risks of work environment factors required high attention(3.99); in particular, noise(4.17), metal particle(4.10), toxic gas(4.10), organic solvent(4.10), high temp-superheat(4.10) were of high risks; hazardous light(3.70) and vibration(3.67) required attention.
Wearing Work Clothes & Safety Gears	 ◆ Under the painting clothes: long sleeved shirt, straight casual pants (P/C blended) ◆ Painting clothes: two-piece type (jumper-type jacket with hoods; cargo pants that tighten the waist and pants hems; P/R blended) ◆ Safety gear: dust-proof mask, safety helmet, protective facial mask, cotton work gloves, protective gloves, arm wristlets, protective shoes)	 ◆ Under the painting clothes: long sleeved shirt, straight casual pants (P/C blended) ◆ Painting clothes: overall one piece-type (overall without hood, adjusting and tightening wrist circumference and pants hems; nylon water-proof fabric) ◆ Safety gear: shoulder length cover hood, facial mask, dust-proof mask, cotton work gloves, water-proof arm wristlets, protective gloves, safety shoes, shoe cover, safety helmet, adhesive blue tapes to cover hems)

average values of such factors as noise, metal particles, vibration, toxic gas, organic compound, UV rays, high temperature and superheat, which are presented in <Table 3>.

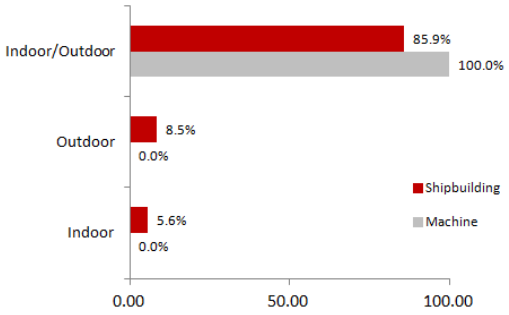
As a result of the ANOVA test, significant difference in averages was found among processes on the level of $p \leq .001$. As to the total average of harmful factors in work environments of the subjects, it turned out that the risk of shipbuilding painting reached 3.99, which was higher than that of machine painting(3.09, a level of 'attention required to the risks'). The results of the comparative analysis of risk indexes of each environmental hazardous factor in both industries are as follows: noise - ship(4.17) > machine(3.26); metal particles - ship(4.10) > machine(3.10); vibration - ship(3.67) > machine(2.77); toxic gas - ship(4.10) > machine(3.30); organic solvent - ship(4.10) > machine(3.20); hazardous light - ship(3.70) > machine(3.00); and high temperature/superheat - ship(4.10) > machine (3.00). Thus, it turned out that the risks of hazardous factors in painting process of shipbuilding were all higher than those of machine industry.

In investigation of the location of workplace, which is in connection with how work clothes would contribute to improving work environments with such functions as heat retention and air permeability, it turned out that 5.6% of shipbuilding painting was done only inside, 8.5% outside, and 86% either inside or outside. 100% of respondents in machine industry answered that they would work either inside or outside <refer to Fig. 7>. As to the assessment of temperature of workplace, 87.0% of shipbuilding painting workers and 63.2% of machine painting workers responded that they would work at high temperature while the proper temperature would be 18 to 23℃ in summer. 94.1% of shipbuilding painting workers and 78.6% of machine painting workers responded that they would work at low temperature in winter, which indicates that both machine and shipbuilding painting workers were unsatisfactory with the air-conditioning of their painting environments <refer to Figures 9 and 10>. In consideration of the fact that there is no air conditioning system within the ship block installed outdoor, it is thought that the work environment of shipbuilding companies, most of

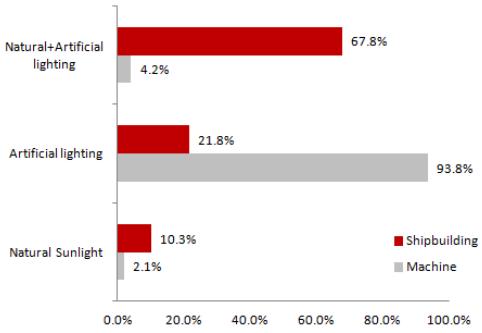
<Table 3> Assessment of risks of work environment hazardous factors to painting workers in the machine and shipbuilding industries

Industry / Hazardous Factors in Work Environments	Machine	Shipbuilding	*F*-value
Noise	3.26	4.17	24.307***
Metal Particles	3.10	4.10	30.201***
Vibration	2.77	3.67	21.387***
Toxic Gas	3.30	4.10	22.969***
Organic Solvent	3.20	4.10	32.284***
Hazardous Light	3.00	3.70	16.297***
High Temp. - superheat	3.00	4.10	52.840***
Total	3.09	3.99	-

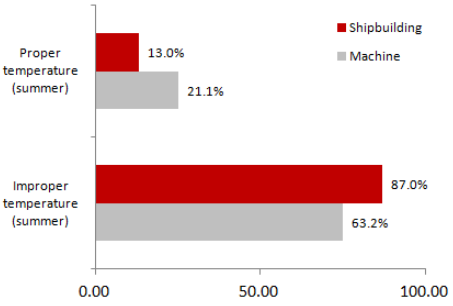
*$p \leq .05$, **$p \leq .01$, ***$p \leq .001$



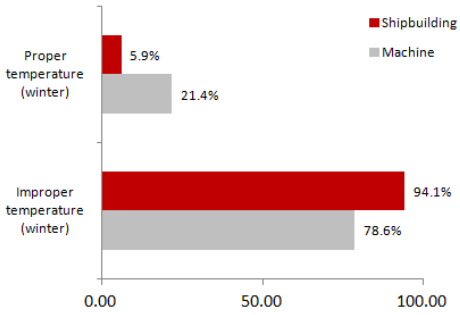
<Fig. 7> Locations(indoor/outdoor) of painting work places in each industry



<Fig. 8> Types of lightings of painting work places in each industry



<Fig. 9> Temperature of workplace of each industry in summer



<Fig. 10> Temperature of workplace of each industry in winter

whose painting work is done outside, is more difficult to adjust the temperature of workplace than that of machine companies.

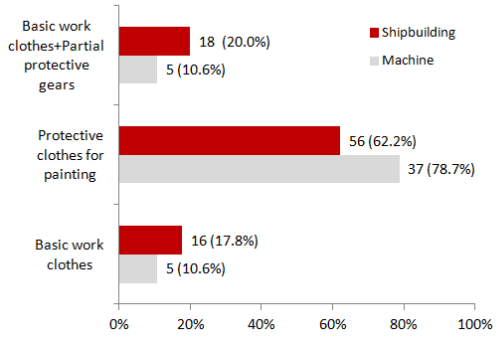
Besides, as to the lighting of painting work environments presented in <Fig. 8>, 2.1% in the machine company and 10.3% in the shipbuilding company stated that they relied on natural sunlight while 4.2% in the machine company and 67.8% in the shipbuilding company on either natural sunlight or artificial lighting. Additionally, utilized were artificial lighting fixtures such as incandescent light, fluorescent light, and halogen lamp. It also turned out that 93.8% of machine painting workers used artificial lighting while 67.8% of shipbuilding painting workers either natural sunlight or artificial lighting.

3. Actual Condition of Subjects' Wearing Work Clothes

<Fig. 11> presents the frequency of wearing only basic work clothes, wearing both basic work clothes and partial protective gears, or wearing protective clothes for painting work to investigate the actual condition of painting workers' wearing work clothes in machine and

shipbuilding industries. The frequency is converted into a percentage in consideration of the number of workers. In the comparative analysis for the two industries, it turned out that 78.7% of machine painting workers would wear protective clothes, and 10.6% both work clothes and partial protective gears, which indicates the high ratio of wearing protective clothes(89.3% in total). However, it also should be noted that 10.6% would wear only the basic work clothes. As to painting workers in shipbuilding industry, it turned out that 62.2% would wear protective clothes for painting, which is lower than the percentage in machine industry, while 20.0% would wear both basic work clothes and partial protective gears, which is higher than the percentage in machine. In total, 82.2% in shipbuilding industry would wear the protective clothes for painting, which was lower than 89.3% in machine industry as to the condition of wearing work clothes for painting. In the case of painting process, the measure of risks in shipbuilding work environments turned out to be higher than that in machine work environments while the ratio of wearing protective clothes of the former was lower than that of the latter. It seems that this is because workers in existing protective clothes for painting were not able to move freely and had difficulties in putting on and taking off such clothes in addition to the deteriorating condition of clothing comfort. Therefore, it is necessary to develop and appropriately supply work clothes and protective clothes that prevent hazardous substances from penetrating and maintain clothing comfort at the same time.

The selected machine and shipbuilding companies were visited, and the pictures of the workplace and workers' wearing work clothes were taken for analysis <refer to Table 2>.



<Fig. 11> Ratio of wearing work clothes and protective clothes among painting workers in each industry

In addition, the existing protective clothes for painting that had been actually used were collected and analyzed in terms of materials for each type of clothes. As a result, it turned out that in the machine industry, polyester and rayon(P/R 65%/35%) blended fabric was used in machine industry while nylon water-proof fabric(Nylon 100%) in shipbuilding industry. As to the types of protective clothes for painting work, used in machine industry were jumpers with front zippers and hoods and loosened cargo pants with waist and pants hems tightened with rubber bands. On the other hand, used in shipbuilding industry were an one-piece type of painting clothes jumper with front zippers and without a hood and overall pants made of nylon water-proof fabric with wrist and pants hems tightened with rubber bands. As to safety gears used for partial protection, used in machine were dust-proof mask, safety helmet, protective facial mask, cotton work gloves, protective gloves, arm wristlet, and protective shoes. Used in shipbuilding industry were hoods covering shoulders, protective facial mask, dust-proof mask, cotton work gloves, water-proof arm wristlet, protective gloves, protective shoes,

protective shoe covers, and safety helmet. The contact with air outside was prevented by means of adhesive blue tapes at every adjusting spots as seen in <Table 2>. Besides, clothes under the outer garments included cotton T-shirts, and casual pants or basic work pants.

4. Analysis of Clothing Comfort and Wearer Mobility

1) Assessment of Clothing Comfort of Work Clothes

For the assessment of clothing comfort of work clothes at each body section among painting workers in machine and shipbuilding, the following aspects were investigated: oppression on chest, limbs, belly, hips; motion functionality of sitting, standing, and moving; senses of putting on and taking off clothes; and physiological comfort including absorption, heat penetration, air permeability, moisture penetration, elasticity and texture of work clothes by using the 5-point scale as mentioned before. When the points fall below 3, the assessment result is negative while the points are above 3, positive. The ANOVA test result on differences of the average values between two industries is presented in <Table 4>.

The assessment results are as follows: oppression on the chest area while the painting worker was wearing work clothes - machine painting(3.87)>shipbuilding painting(3.50), which indicates painting workers in shipbuilding feel more uncomfortable; oppression on limbs - machine painting(4.09) > shipbuilding painting (3.54); oppression on the belly machine painting (4.04) > shipbuilding painting(3.59); and oppression on hips - machine painting(4.11) > shipbuilding painting(3.54) in the order. In general, it turned out that painting workers in machine industry felt more comfortable. However, the average values regarding oppression on body parts while the workers are wearing work clothes were 3.0 or higher in both industries, which indicates that the work clothes in terms of oppression were comfortable enough.

In contrast with the assessment results of the clothing comfort in terms of oppression, the results of assessments of motion functionality for sitting, standing, and moving and of the senses of putting on and taking off show the clothing discomfort in the range of 2.65 to 2.85.

<Table 4> Assessment of work clothes clothing comfort among painting workers in the machine and shipbuilding industries

Industry / Clothing Comfort Assessment	Machine	Shipbuilding	*F*-value
Oppression on Chest	3.87	3.50	5.253*
Oppression on Limbs	4.09	3.54	10.832***
Oppression on Belly	4.04	3.59	7.739**
Oppression on Hips	4.11	3.54	11.813***
Sitting and Standing	2.68	2.67	.004
Movement	2.85	2.65	1.720
Putting on and Taking off	2.72	2.77	.089

*$p \leq .05$, **$p \leq .01$, ***$p \leq .001$

<Table 5> Assessment of work clothes physiological clothing comfort among painting workers in the machine and shipbuilding industries

Industry / Physiological Comfort Assessment	Machine	Shipbuilding	*F*-value
Water Absorption	2.28	2.33	.113
Heat Penetration	2.13	2.44	3.815
Air Permeability	2.06	2.51	7.115**
Moisture Penetration	2.02	2.34	4.003*
Elasticity	2.13	2.45	3.494
Texture	2.36	2.44	.243

*$p \leq .05$, **$p \leq .01$, ***$p \leq .001$

Painting workers in machine and shipbuilding industries assessed the physiological comfort of work clothes, and the results are presented in <Table 5> for each industry. In investigation of the general physiological clothing comfort, the painting workers in machine and shipbuilding industries assessed as 'uncomfortable,' lower than 'normal' all factors such as water absorption, heat penetration, air permeability, moisture penetration, elasticity, and texture. As in the results above, it turned out that protective clothes for painting mainly focused on the function to prevent organic solvents or toxic gas from penetrating into the human body, but the clothing comfort was evaluated as low. Thus, even though the workers were aware of the seriousness of hazardous factors in painting process environments(in the 5-point scale of risks, 3.09 as to machine industry and 3.99 as to shipbuilding, both of which are higher than normal), 10.6% and 17.8% in machine industry and shipbuilding industries respectively would simply wear basic work clothes, rather than protective clothes for painting work <refer to Table 3 and Fig. 11>.

As shown above, painting workers' clothing comfort with the work clothes in machine and shipbuilding industries was classified for specific assessment to motion functionality including oppression on body parts, senses of clothing comfort, and physiological clothing comfort. As a result, painting workers in both industries evaluated the tightness as 'comfortable', while evaluating motion functionality and senses of putting on and taking off as 'uncomfortable'. As to physiological clothing comfort, painting workers in both machine and shipbuilding industries, whose percentage of wearing protective clothes was high, evaluated it as 'uncomfortable', whose score is lower than that of 'normal'.

2) Assessment of Motion Functionality Based on the Index of Clothing Discomfort for Each Work Clothes Area

To confirm the extent of clothing discomfort while a worker wore work clothes, the clothes were divided to upper part and lower part from the waist line as the reference point. Analyzed were the responds specifying certain areas of clothing discomfort among the following: neck circumference, biacromial breadth, armhole length, jumper front and back lengths, sleeve circumference, sleeve length, sleeve hems of the jumper, waist, hip circumferences, body rise,

thigh, knee circumferences, pants hems, and pants length of the pants. <Table 6> shows the frequency of uncomfortable feelings in general and at each area of work clothes during painting work in machine and shipbuilding industries. The frequency values are expressed as a percentage based on the number of workers in each process. Then the percentages of the uncomfortable feeling frequency among the entire subject workers for each part of work clothes were classified from grade 1 to 20 at 5% intervals. Each index for the 20 grades indicates the following respectively: 0~5% - index 1; 6~10% - index 2; …, 91~95% - index 19; and 96~100% - index 20. The results are presented in <Table 7>. The darkest shadow area indicates the index of grades 9 to 12, which means that 45~60% of the workers responded, "uncomfortable." The less dark shadow area indicates the index of grades 5 to 8, which means 25~40% of the workers responded, "uncomfortable." Uncomfortable areas to be noted are examined in reference to this information in terms of working motion functionality.

As to the index of work clothes clothing discomfort in general, in machine industry painting process with the two-piece type painting work clothes, the index of clothing discomfort was grade 3 to 5 while in shipbuilding painting with coveralls grade 8 or higher. As to the index of clothing discomfort of upper/lower/upper and lower total parts of work clothes in general, in machine industry painting work, the index was 3/4/4 respectively while in shipbuilding painting, 8/9/9 respectively, which indicates that the latter's is a lot higher, and the index of lower clothes parts is higher than that

<Table 6> Frequency and percentage of the work clothes discomfort parts answered by subject painting workers

Evaluations \ Industry		Machine(N=48)		Shipbuilding(N=91)		χ^2
		Frequency	Frequency of clothing discomfort/ Total No. of Workers(%)	Frequency	Frequency of clothing discomfort/ Total No. of Workers(%)	
Jumper	Neck Circumference	8	16.7	36	39.6	57.642***
	Biacromial Breadth	8	16.7	39	42.9	42.889***
	Armhole Length	8	16.7	46	50.5	37.922***
	Jumper Front Length	8	16.7	35	38.5	35.825***
	Jumper Back Length	9	18.8	36	39.6	41.181***
	Sleeve Circumference	6	12.5	38	41.8	28.840**
	Sleeve Length	10	20.8	39	42.9	36.544***
	Sleeves Hems	8	16.7	36	39.6	44.486***
Pants	Waist Circumference	13	27.1	42	46.2	43.475***
	Hip Circumference	8	16.7	41	45.1	36.945***
	Body Rise	13	27.1	43	47.3	30.528***
	Thigh Circumference	8	16.7	40	44.0	36.673***
	Knee Circumference	9	18.8	37	40.7	42.259***
	Pants Hems	8	16.7	37	40.7	33.935***
	Pants Length	11	22.9	49	53.8	37.103***

*$p \leq .05$, **$p \leq .01$, ***$p \leq .001$

<Table 7> 20 grades of clothing discomfort index for each part of painting work clothes in the machine and shipbuilding industries

Evaluations \ Industry		Machine	Shipbuilding
Jumper	Neck Circumference	3	8
	Biacromial Breadth	3	9
	Armhole Length	3	10
	Jumper Front Length	3	8
	Jumper Back Length	4	8
	Sleeve Circumference	3	8
	Sleeve Length	4	9
	Sleeve Hems	3	8
	Average Index of Clothing Discomfort of Upper Clothes Parts	3	8
Pants	Waist Circumference	5	9
	Hip Circumference	3	9
	Body Rise	5	9
	Thigh Circumference	3	9
	Knee Circumference	4	8
	Pants Hems	3	8
	Pants Length	5	11
	Average Index of Clothing Discomfort of Lower Clothes Parts	4	9
Average Index of Clothing Discomfort of Total Upper and Lower Clothes Parts		4	9

20 Levels at 5%-intervals of the percentages of answering 'uncomfortable' of workers
□: Index 4 or less; □: Index 5~8; □: Index 9~12 of 20 grades of clothing discomfort index

of upper clothes parts in both industries. Additionally, in the preliminary study[8] on the index of clothing discomfort of work clothes used in welding and grinding processes of machine and shipbuilding industries, the index of clothing discomfort of upper/lower/upper and lower parts in shipbuilding welding was 6/6/6, shipbuilding grinding 5/5/5, machine welding 4/4/4, and machine grinding 1/1/1 in the order respectively. It seems that this preliminary study result could be the criteria to comparatively judge the index of clothing discomfort of painting work clothes addressed in this study. While the index of clothing discomfort of machine painting work clothes was as high as that of the index of the welding process in the same industry, the index of clothing discomfort of shipbuilding painting work clothes was far higher than those of other processes. It is thought that this is because the upper body part motions and lower part motions are affecting each other when shipbuilding painting workers in coverall type protective clothes make various moves with the range of movement restricted by putting on adhesive blue tape on all sleeves' and pants' hems.

The average index of clothing discomfort of work clothes in shipbuilding painting work was

grade 9 for the upper and lower parts of clothes. More specifically, the index of all clothes parts was high up to 8~11, and in particular, that of the upper parts' armhole length was 10, and briacromial breadth and sleeve length grade 9 respectively, which were the highest. As to lower parts, the index of pants length was grade 11, which was the highest among all while those of waist circumference, hip circumference, body rise, and thigh circumference were grade 9, and knee circumference and pants hems grade 8 respectively. In the machine painting process, the index of jumper back length and sleeve length was grade 4, which was the highest among upper parts while in the lower parts, those of waist circumference, body rise, and pants length were grade 5, and knee circumference grade 4 in the order. Sections of biacromial breadth, armhole length, and sleeve length, which were regarded as the most uncomfortable of upper parts, are in relation to the motions of the upper body part involving arm movements while the back length of the upper clothes parts is in relation to the position to bend the back. For such motions, the maximum body extended rate should be reflected in the development of work clothes. The lower parts of work clothes such as body rise and waist, hip, thigh and knee circumferences should be taken into consideration along with various work poses and motions of the lower body part for further study. The task for future study to develop functional work clothes designs should meet the requirements that reflect the extension rates of the upper and lower body parts and the garment ease should be enough not to hinder working motions at the same time.

IV. Conclusion

Painting process of machine and shipbuilding industries was selected as the subject in this study because the extent of harmfulness of working environment factors such as organic solvents, toxic gas, oxygen deficiency, and workplace temperature was the largest while that of metal particles was the lowest among the 4 categories of work process, whose working processes were classified as similar to each other among the 12 processes of machine, automobile, and shipbuilding in domestic heavy industry areas addressed in preliminary studies[9]. The painting processes of machine and shipbuilding industries have similarities and differences at the same time. The results of preliminary study on characteristics of work environment and worker's motions in painting process should be diversified in view of wearing work clothes and taken into consideration along with the index of clothing comfort and clothing discomfort of each area of work clothes in order to gain significant study results for the development of specialized painting work clothes for the machine and shipbuilding industries. As the results of motion functionalities by analyzing work environment characteristics, actual condition of wearing work clothes, clothing comfort and clothing discomfort of work clothes are summarized and associated with the development of functional painting work clothes, the suggestions regarding functions, design, and production methods of protective clothes for painting workers in machine and shipbuilding process are as follows:

It turned out that as to work environments of painting process in machine and shipbuilding industries, the index of hazardous environmental factors such as temperature, organic solvents,

toxic gas, and oxygen deficiency was higher than any other processes, which indicates the necessity of wearing special protective clothes over the basic work clothes. As to painting process, special protective clothes should be worn over the basic work clothes, and when spray painting was involved, the protective clothes for painting worn for 2 or 3 days were disposed instead of being washed. As protective clothes for painting continue to be used, the coating paints adhere to the surface of work clothes, which deteriorates the senses of putting on and taking off and motion functionalities, and thus the index of clothing discomfort increases accordingly. For the same reason, the risks due to hazardous factors of working environments were high both in shipbuilding and machine industries, but painting workers in shipbuilding industry, 17.8% of whom would wear only basic work clothes without protective clothes, need to be given a specialized type of protective clothes for painting process. Although pre-treatment or spray work requires water-proof materials of outstanding liquid-resistance, there is no need to use the same materials for touch-up workers since the use may deteriorate their physiological clothing comfort. In particular, for painting workers who mainly work in a place where it is difficult to control the temperature, required are work clothes of which material and design are excellent at air permeability and moisture penetration. The two-piece type painting work clothes used in the machine painting process and plus the materials of high water repellent performance required for the painting work environment could be a solution for touch-up painting workers in shipbuilding industry. In the study of Bae et al[10], the comparative investigation on the materials of woven nylon and non-woven polypropylene for protective clothes for painting shows that non-woven polypropylene was better regarding air permeability and water repellent while nylon was better than the former resistance against water and organic solvent as well as tensile strength and tearing strength. After all, nylon was suggested in consideration of its tensile strength and tearing strength which are required in painting work environments in the heavy industry where various working motions are necessary and handling of steel materials is also unavoidable. Although the nylon materials used in current protective clothes for painting are water-proof but not enough air permeability, expensive materials of high water-proof and air permeability such as GORE-TEX® are not used due to the high production cost. To mind this, coated nylon materials of higher water-proof and air permeability performance improved for protective clothes for spray painting could secure the essential properties, tensile and tearing strength.

As the painting process in shipbuilding industry shows higher index of risks of hazardous factors in working environments than in machine industry, the ratio of wearing protective clothes/safety gears in machine industry is 89.3%, which is higher than 82.2%, the ratio in shipbuilding painting process. As to oppression on the body while wearing work clothes, the respondents marked on 'normal' to 'comfortable' in both machine and shipbuilding industries, but on 'uncomfortable' regarding movement and senses of putting on and taking off. Therefore, it is vital to improve elasticity for better motion functionality. As to the index of clothing discomfort of each area of work clothes, it turned out that wearing protective clothes for painting to protect the human body from hazardous factors in dangerous working

environment in shipbuilding painting process would rather deteriorate the motion functionality. As a result, the index of clothing discomfort of every area of work clothes was grade 8 to 11 of 20 grades among the workers in the process. Especially, the index of clothing discomfort of the upper clothes' armhole length was grade 10, and those of biacromial breadth and sleeve length grade 9 respectively. For these areas of work clothes, whose index of clothing discomfort was the highest, motions of stretching out the arms need to be considered in the work clothes development. As to lower parts of work clothes, the index of clothing discomfort of body rise and pants length turned out to be high. Thus, for working motions of the lower body, extension of body parts during the motions of bending the knees, crouching, stretching out the legs needs to be considered in the work clothes development. In addition, as to jumper front length, jumper back length, sleeve circumference of the upper clothes and waist, hip, thigh, knee circumferences and body rise of the lower clothes, such excessive motions as crouching, facing down with the body twisted, frequent movement, and bending at various angles also should be considered along with working motion factors[11]. In the preliminary study[12], the working motions of workers in machine, automobile, and shipbuilding industries were categorized according to three attribute types, i.e. upper, lower and sides body movement. The frequency and angles of each motion type were analyzed to measure the index of influence on working motions. With the range from 1 to 5, the index of working motions of painting workers in machine industry was 3 for the upper body, 4 for the lower body, and 4 for the sides movement while the index of painting workers in shipbuilding industry was 4 for the upper body, 3 for the lower body, and 5 for the sides movement. Especially high was the index of motions of twisting the body to the sides. In addition to the comprehensive analysis of the results on working motion functionality, developing the work and protective clothes in reflection of the shipbuilding painting process, whose index of clothing discomfort in all clothes parts was high, would solve problems of motion functionality that may occur as the ratio of wearing protective clothes increases. For instance, it is necessary to suggest designs that enhance elasticity over the biacromial breadth, which was one of the inconvenient parts upon bending or twisting, and to consider the increase of jumper back length and armhole depth. For working process where crouching motions are found frequently, extending jumper back length to the hip length level longer than jumper front length in the case of wearing the two-piece type painting clothes will lower the index of clothing discomfort. With regard to the high index of clothing discomfort over body rise, as the protective clothes are usually worn over basic working pants, extending body rise of both basic work clothes and protective clothes for painting will make it easy to making various motions freely.

The female workers in painting process make up 35% of the entire work force, which indicates a considerable number of workers are women, but no special type of clothes in either common work clothes or special protective clothes for painting has been developed, and the clothes have been worn without separation of men and women. This issue needs to be addressed urgently as the entire workers, 65% of whom were men, evaluated their work clothes mobility as very low.

Based on the comprehensive investigation on

the actual condition of wearing work clothes among painting workers in machine and shipbuilding industries selected for this study in view of the hazardous factors in working environments, clothing comfort, and motion functionality, the future study needs to develop high performance protective clothes and basic work clothes both whose protective and motion functionalities are enhanced for the painting process. In addition, the method to classify the attributes of working process for the basis of developing work clothes could be utilized again to evaluate the performance of newly developed work clothes.

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