The Classification of Manufacturing Work Processes to Develop Functional Work Clothes⁺

– With a Reference to the Automobile, Machine and
Shipbuilding Industries –

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Abstract

In consideration of the injuries and deaths occurring at manufacturing sites due to the use of inappropriate work clothes or safety devices, this study aims to categorize manufacturing work processes to develop functional work clothes for heavy industries including the automobile, machine and shipbuilding industries in South Korea. Defining the features of the work environments and work postures of these industries provided for a categorization of the work processes which would enable the development of suitable work clothes for each work process' category. The results of the study based on a questionnaire survey are as follows: Work process category 1, including steel panel pressing and auto body assembly, final inspection (in automobile) and inspection (in machine), requires work clothes with upper body and arm mobility and performance to protect from the toxic fume factor. Work process category 2, consisting of welding (in automobile), cutting-and-forming (in machine) and attachment-and-construction (in shipbuilding), requires clothing elasticity, durability and heat and fire resistance. Work process category 3 comprising welding and grinding in the machine and shipbuilding industries, requires work clothes' tear resistance and elasticity, particularly for lateral bending mobility, and work clothes' sleeves' and pants' hemlines with sealed designs to defend against iron filing penetration, as well as incombustible and heat-resistant material performance. Finally, work process category 4, including painting in machine and shipbuilding, requires work clothes with waterproofing, air permeability, thermal performance, elasticity, durability and abrasion resistance.

Key Words : work clothes, work environment, work postures, wearer mobility, manufacturing work processes in the automobile, machine and shipbuilding industries

⁺ This work has been supported by Changwon National University 2011~2012 Research Grant Fund.

I. Introduction

In South Korea, heavy industries such as automobile, machine, and shipbuilding manufacturers produced about 23.5% of the total national annual production in the year 2008¹⁾. However, every year tens of thousands of workers receive injuries while performing their jobs at the manufacturing sites and thousands of them die. It is reported that there have been injuries and illnesses due to muscle, joint and bone disorders from physical jobs, as well as skin ailments or respiratory diseases caused by contacting or inhaling toxic substances emitted from the work environment, which consequently caused negative effects on workers' health, and even loss of life. In addition to this there is a cost to employers in terms workers' compensation charges.

To improve manufacturing work environments, employers should keep reducing the hazardous work environment factors in their work places. The workers, in turn, ought to follow industrial safety regulations during work time, including wearing appropriate work clothes or safety gear according to the features of the work processes. In terms of work safety, work clothes fall under the category of functional garments to protect the human body from hazardous environmental factors and assist workers in performing their jobs. The work clothes for the manufacturing industries must have wearing comfort and wearer mobility, in addition to having the neat and smooth appearance of daily clothing²⁾. Moreover, if a worker wears inappropriate work clothes to his work station, it may cause various types of injuries. Examples of these injuries in the heavy industries, such as musculoskeletal disorders, slip and fall accidents, crush injuries, lacerations, burns, skin ailments, toxic

substances accumulation in the body, respiratory diseases, etc. have been reported by the Korea Occupational Safety and Health Agency³⁾.

Up until now, the research about work clothes^{4~5)} in the automobile, machine and shipbuilding industries in South Korea has indicated that all the employees of the subject heavy industry companies in the research wore the same kind of work clothes, since the manufacturing workers asked for the very same work clothes, in order to make themselves look equal to other employees⁶⁾. However, even within a single industry, as the features of work environments and work postures of various work processes differ, the workers at the manufacturing sites need to wear specialized work clothes which account for the characteristics of each work process. At the moment, manufacturing workers have come to a compromise, i.e. they wear non-specialized work clothes with various types of safety gear (e.g. wristlets, gaiters, aprons, overalls for painting, safety vests, fire-proof jackets/pants/overalls, safety helmets, gas masks, eye protecting goggles, ear caps, safety gloves, safety shoes, etc.) to protect against certain hazardous environmental factors⁷⁾. Although these safety accessories can offer a certain amount of protection for the workers, if the work clothes they wear under the protective garments or devices fail to afford the wearer the mobility required, or the properties of materials used for the work clothes are unsuitable for the features of work environments, these safety accessories can no longer suitably perform the functions of protecting the body. Therefore, the work clothes for manufacturing workers should offer wearer mobility according to work posture features and functionality against hazardous work environments. In order to deal with this kind of

problem occurring at manufacturing sites, this study aims to propose guidelines to develop functional work clothes for heavy industries through the classification of manufacturing work processes taking account of the features of the work environment and work postures of the automobile, machine and shipbuilding industries in South Korea.

II. Methods

1. Subject Companies in Heavy Industry

To determine the impact levels of work environment factors by the work processes within the automobile, machine and shipbuilding industries, a major company from each of these three types of industry was selected for the study: i.e. G company in automobile, D company in machine and C company in shipbuilding; the initial standing for the company names. The subject companies are located in the national industrial complex in the southern province of Gyeongsangnam-do, South Korea. Given that they were the leading companies in the relevant industries, it was assumed that the conditions of their manufacturing work environment might be representative of companies of the same kind. The face-to-face structured interview surveyed managerial staff of the subject companies to define their manufacturing work processes. The interview for the study consisted of questions about work processes carried out at manufacturing sites, types of work clothes and safety clothing/devices that they provided, etc. Three sets of interviews were conducted during the period of February 2009.

2. Questionnaires to Determine the Impact Levels of Work Environment Factors

The study analyzed the investigation of the twelve work processes of the automobile (i.e. steel panel press, car frame welding, car body assembly and final inspection processes of G company), machine (cutting-and-forming, welding, painting and inspection processes of D company) and shipbuilding (attachment-and-construction, welding, grinding and painting processes of C company) industries based on the previous research⁸⁾. The impact levels of work environment factors were determined according to the statistics derived from a questionnaire survey conducted between May and June 2009, which consisted of questions about the assessment of physical work environment factors⁹⁾. All questions were designed to survey the manufacturing workers' subjective assessment of the physical work environment factors. They were answered on a five-point scale in a range from 1 ('very low' impact level), through 3 ('moderate' impact level) to 5 ('very high' impact level). The physical work environment factors considered in the questionnaire were: fume, organic solvents, UV ray, superheat, toxic gas, metal fragment, workplace temperature, oxygen deficiency (except the noise factor since it was not considered as in direct relation with the development of work clothes). The respondents of the questionnaire were 199, 129 and 336 workers of G, D and C companies respectively, for a total of 664 respondents.

3. Observational Technique to Determine the Impact Levels of Work Posture Factors

To identify the work posture factors and to

determine the impact levels of the ergonomic factors of the relevant work processes in these three companies' manufacturing sites, an observational technique was implemented in the study. The observational technique was chosen as it was not considered to interfere with workers during observations, nor did it require the use of expensive equipment for estimating the angular deviation of a body from the neutral position¹⁰⁾. Most postural classification schemes are based on observation methods and, therefore, it is said that this technique is more wide spread both in relevant academia and industries. Examples of the valid schemes are posture targeting, OWAS, REBA, RULA¹¹⁾ and of these techniques, OWAS, REBA and RULA schemes were implemented in this study. During the period from February to April 2009, the subject companies' manufacturing work postures were recorded using a video camera and analyzed by the use of a multimedia video task analysis tool (MVTATM, Ergonomics Analysis and Design Consortium, Released in 2005)¹²⁾. To evaluate the ergonomic impact levels of workers' motions in the work processes, in particular, three work postural factors were identified according to the body parts used, i.e. the upper body bending, lower body bending and lateral body bending factors. Regarding the impact levels of the postural factors, the evaluation was presented in a range from 1 ('very low' impact level), through 3 ('moderate' impact level) to 5 ('very high' impact level) by estimating the numbers and degrees of the worker's upper, lower or lateral body bending actions. The determination of the impact levels of the work environment and work posture factors of these industries would enable classification of the heavy industrial work processes into categories according to the similarity of these identified

work processes' characteristics.

III. Results and Discussion

1. Work Processes Defined at Heavy Industrial Manufacturing Sites

Table 1 identifies the twelve manufacturing work processes of the automobile, machine and shipbuilding industries defined through the face-to-face structured interviews; and displays photos of these work processes taken at the manufacturing sites of the subject companies. The automobile industry consisted of the semi-automated processes of steel panel pressing and car frame welding and the labour intensive processes of car body assembly and final inspection (processes No. 1 to 4 refer to Table 2). Since the painting process in the automobile industry was carried out through the 100-percent automatic manufacture system, this process was excluded from the analysis. The machine industry was identified to have cutting-and-forming, welding, painting and inspection processes (processes No. 5 to 8 refer to Table 2). The shipbuilding industry consisted of attachment-and-construction, welding, grinding and painting processes (processes No. 9 to 12, refer to Table 2).

2. The Impact Levels of Work Environment Factors on the Work Processes Defined

The impact levels of work environment factors were based on the five-point scale rates from subject workers' assessments of the questions about work environment factors. All the rates were significant at the level of $p \leq .001$ through the ANOVA test and each rate was rounded off to the nearest whole number. Table 2 presents

<Table 1> Manufacturing work processes defined within the (A) automobile, (M) machine and (S) shipbuilding industries in South Korea

Industry	Work processes			
(A) Automobile	Pressing	Welding	Assembly	Inspection

(M) Machine	Cutting-and-Forming	Welding	Painting	Inspection

(S) Shipbuilding	Attachment-and-construction	Welding	Grinding	Painting

the results according to each featured work environment of these heavy industries work processes. The comparison of the average impact levels of the total work environment factors in these three industries shows that the shipbuilding industry has the most hazardous work environment with all its factors rated as 4 ('high') among the subject companies. It was followed in rank by the machine industry and the automobile industry respectively.

The manufacturing work processes of the shipbuilding industry were the attachment-and-construction (for the block assembly), welding,

grinding and painting processes. The impact levels of work environment factors in the shipyard (refer to Table 2) were analyzed as the highest among the subject companies. The workplace temperature impact levels were between 4 ('high') and 5 ('very high') and this was because the shipbuilding work places were located in an outdoor area undoubtedly without air conditioning systems; the metal fragment factor impact levels were 5 ('very high') in the processes of attachment-and-construction, welding and grinding. The attachment-and-construction process had 'high' and 'very high'

impact levels of work environment factors, excluding organic solvent and oxygen deficiency factors. The work process having the most hazardous work environment was welding in the shipbuilding industry as its impact levels of all work environment factors were 4 and 5. The analysis of the painting process was also similar to that of welding, but in exception the metal fragment factor showed a 'low' impact level of 2 in the painting work process. Note that the grinding process had 'moderate' impact levels of organic solvent, UV ray and toxic gas factors, and 'high' and 'very high' impact levels of fume, superheat, metal fragment, workplace temperature and oxygen deficiency factors.

The machine industry comprised mainly four work processes, including steel plate cutting-and-forming, welding, painting and the final inspection processes (refer to Table 2). The welding process had 'high' impact levels of most work environment factors excluding organic solvent factor rated 3 ('moderate'). 'High' impact levels of fume, superheat, toxic gas and work place temperature factors on the cutting-and-forming process were also indicated. On the other hand, the inspection process had 'low' and 'moderate' work environment impact levels evaluated between 2 and 3, yet a 'high' impact level of fume factor was shown. The average impact levels of total work environment factors,

<Table 2> The impact levels of work environment factors in automobile, machine and shipbuilding industries manufacturing work processes

Industry	Automobile				Machine				Shipbuilding			
Work Process No	1	2	3	4	5	6	7	8	9	10	11	12
Work process Work environment factors	Pressing	Welding	Assembly	Inspect-ion	Cut-and-Form.	Welding	Painting	Inspect-ion	Attach.-and-Cons.	Welding	Grinding	Painting
Fume	3	4	3	3	4	4	3	4	4	4	4	4
Organic solvent	3	3	2	2	3	3	3	3	3	4	3	4
UV ray	3	3	2	2	3	4	3	3	4	4	3	4
Superheat	3	3	2	3	4	4	3	3	4	4	4	4
Toxic gas	3	3	3	3	4	4	3	3	4	4	3	4
Metal fragment	2	4	2	2	3	4	2	2	5	5	5	2
Workplace temperature	3	3	3	3	4	4	4	3	4	5	5	5
Oxygen deficiency	2	2	2	2	3	4	4	2	2	4	4	4
Average impact level of total work environment factors	3	3	2	3	3	4	3	3	4	4	4	4

Note: Impact level 1 – Very low; 2 – Low; 3 – Moderate; 4 – High; 5 – Very high

i.e. 'moderate' in cutting-and-forming, painting and the final inspection work processes, but 'high' in the welding process of the machine industry, were by and large higher than those of the automobile industry.

In the automobile industry (refer to Table 2), the impact levels of the work place temperature factor for all processes were 3 ('moderate'); the super high heat factor's impact levels were in the range between 2 and 3 (or 'low' and 'moderate'); the impact levels of the toxic gas, organic solvents, oxygen deficiency, metal fragment, and UV ray factors were 2 and 3 (between 'low' and 'moderate') throughout all the processes. The welding process alone at the automobile manufacturing sites indicated consistently 'high' impact levels of the toxic fume and metal fragment factors, i.e. 4 ('high'). The average impact levels of total work environment factors in the automobile industry were between 'low' and 'moderate' for all work processes.

Figure 1 shows the work environment factor impact levels of all twelve work processes in the form of radar charts, the tendency of which, in turn, enabled the classification of the work processes into four categories demonstrated in Figures 2 to 5. Work process category 1 (refer to Figure 2) includes pressing, assembly, inspection (in automobile) and inspection (in machine), and its work environment is relatively safe in comparison with other work process categories. Its work environment impact level tendency presents 'low' impact levels of oxygen deficiency and metal fragment factors and 'moderate' impact levels of organic solvent, UV ray, superheat, toxic gas, workplace temperature and fume factors. However, it should be noticed that the fume factor impact level in the inspection process in the machine industry was

consistently 'high'.

Work process category 2 (refer to Figure 3) consists of three work processes: welding (in automobile), cutting-and-forming (in machine) and attachment-and-construction (in shipbuilding) and its work environment is more harmful than that of work process category 1. The impact levels of oxygen deficiency and organic solvent factors are 'low' and 'moderate', as these processes were performed in outdoor areas or at an indoor work place controlled by a ventilation duct system. For the same reason, the impact levels of the workplace temperature factor of these processes were 'high' which means it is difficult to control the workplace temperature; thus its workers may need clothing with high air permeability. In addition, the impact levels of UV ray, superheat and toxic gas factors were 'moderate' to 'high'. However, the fume factor impact levels on the work process category 2 were 'high', and in particular the metal fragment impact level of the shipbuilding attachment-and-construction process was 'very high'. As a consequence, this work process category may require special work clothes designed to protect workers from metal fragments.

The work environment impact levels of work process category 3 (refer to Figure 4) reveal a highly hazardous tendency throughout all the work environment factors rated 'high' to 'very high' excluding the organic solvent factor rated between 'moderate' and 'high'. This category includes the work processes of welding (in machine) and welding and grinding (in shipbuilding) which are under the poorest conditions.

Figure 5 shows the work process category 4, including the painting processes in the machine and shipbuilding industries. It has 'high' and

'very high' impact levels of workplace temperature and oxygen deficiency factors, and 'moderate' to 'high' impact levels of organic solvent, toxic gas and fume factors, etc. The metal fragment work environment factor only impacts 'low' in the painting processes of this category. Painting work was carried out in an outdoor work place and the work clothes for this

work should meet high performance of waterproofing and air permeability, as well as thermal performance in winter.

(A) Automobile industry work processes: pressing (work process #1), welding (work process #2), assembly (work process #3), and inspection (work process #4)

(M) Machine industry work processes: cutting-and-forming (work process #5), welding (work process #6), painting (work process #7) and inspection (work process #8)

(S) Shipbuilding industry work processes: attachment-and-construction (work process #9), welding (work process #10), grinding (work process #11) and painting (work process #12)

Note: Impact level 1 – Very low; 2 – Low; 3 – Moderate; 4 – High; 5 – Very high

<Figure 1> The impact level radar charts of work environmental factors of (A) automobile, (M) machine and (S) shipbuilding industry manufacturing work processes

Note: Impact level 1 – Very low; 2 – Low; 3 – Moderate; 4 – High; 5 – Very high

<Figure 2> The work process category 1 including the work environment factor impact level radar charts nested of pressing, assembly, inspection (in automobile) and inspection (in machine) processes

Note: Impact level 1 – Very low; 2 – Low; 3 – Moderate; 4 – High; 5 – Very high

<Figure 3> The work process category 2 including the work environment factor impact level radar charts nested of welding (in automobile), cutting-and-forming (in machine) and attachment-and-construction (in shipbuilding) processes

Note: Impact level 1 – Very low; 2 – Low; 3 – Moderate; 4 – High; 5 – Very high

<Figure 4> The work process category 3 including the work environment factor impact level radar charts of welding (machine) and welding and grinding (shipbuilding) processes

Note: Impact level 1 – Very low; 2 – Low; 3 – Moderate; 4 – High; 5 – Very high

<Figure 5> The work process category 4 including the work environment factor impact level radar charts of painting (machine) and painting (shipbuilding) processes

3. The Impact Levels of Work Posture Factors in the Work Processes Defined

Table 3 presents the impact levels of the work postural factors which are upper, lower and lateral body bending in the twelve work processes defined in the study. To see the average impact levels of total work posture factors, all of the work processes of the machine industry (work processes No. 5 to 8) showed 'high' average impact levels. The average work postural impact levels in three shipbuilding work processes (work processes No. 9, 11 and 12) were 'high', besides the 'moderate' average impact level in the welding process (work process No.10). Finally, the three work processes in the automobile industry (work processes No.1, 3 and 4) were rated between 'low' and 'moderate', whereas the welding process (work process No. 2) alone had a 'high'

average impact level in this industry.

The impact levels of each work postural factor in the twelve work processes varied in a range from 2 ('low') to 5 ('very high') as shown in Table. 3. The consideration of the rating of each body part's bending factor within each work process helped to classify these twelve work processes into three types (refer to Table 4). Table 4 explains that first, the work processes emphasizing the upper body bending factor were assembly, inspection, pressing (in automobile), and grinding and painting (in shipbuilding). Second, the work processes emphasizing the lower body bending factor included welding (in shipbuilding) and painting (in machine). Third, the work processes which equally emphasized the upper and lower body bending factors were cutting-and-forming, welding, inspection (in machine), attachment-and-construction (in shipbuilding) and welding (in automobile).

<Table 3> The impact levels of the work postural factors in automobile, machine and shipbuilding manufacturing work processes

Industry	Automobile				Machine				Shipbuilding			
Work Process No	1	2	3	4	5	6	7	8	9	10	11	12
Work process Work postural factors	Pressing	Welding	Assembly	Inspect- ion	Cut- and- Form.	Welding	Painting	Inspect- ion	Attach.- and- Cons.	Welding	Grinding	Painting
Upper body bending	4	<u>5</u>	3	4	4	4	3	4	4	2	4	4
Lower body bending	3	4	2	2	4	<u>5</u>	4	<u>5</u>	4	3	3	3
Lateral body bending	2	3	2	2	3	4	4	3	3	4	4	<u>5</u>
Average impact level of total work postural factors	3	4	2	3	4	4	4	4	4	3	4	4

Note: Impact level 1 – Very low; 2 – Low; 3 – Moderate; 4 – High; 5 – Very high

<Table 4> The classification of automobile, machine and shipbuilding manufacturing work processes by featuring the work posture characteristics

Upper body bending factor emphasized work processes				Lower body bending factor emphasized work processes				Upper & lower body bending factors equally emphasized work processes			
Work process	Impact levels of work posture factors			Work process	Impact levels of work posture factors			Work process	Impact levels of work posture factors		
	Upper body	Lower body	Lateral body		Upper body	Lower body	Lateral body		Upper body	Lower body	Lateral body
(A)Assembly	3	2	2	(S)Welding	2	3	4	(M) Cut-and-Form	4	4	3
(A)Inspection	4	2	2	(M)Painting	3	4	4	(S)Attach.-and-Cons.	4	4	3
(A)Pressing	4	3	2					(M)Inspection	4	5	3
(S)Grinding	4	3	4					(M)Welding	4	5	4
(S)Painting	4	3	5					(A)Welding	5	4	3

Note: Impact level 1 – Very low; 2 – Low; 3 – Moderate; 4 – High; 5 – Very high

In addition to the above, the lateral bending factor needs to be considered in association with upper and lower body bending mobility. For example, the upper body bending factor was emphasized in grinding and painting processes (in shipbuilding); the lower body bending factor was emphasized in welding (in shipbuilding) and painting processes (in machine); and welding (in machine), where the upper and lower body bending factors were equally emphasized, these processes also had 'high' or 'very high' impact levels of the lateral body bending factor. It is, therefore, important to note that these work processes may demand special work clothes designed to provide workers with enhanced lateral bending mobility, as well as upper or lower body bending mobility.

IV. Conclusion

According to the analysis of the physical work

environment and the work postures of the automobile, machine and shipbuilding industries selected for this study, the work environment features derived from the results enabled a classification of these twelve heavy industrial manufacturing work processes into four categories (refer to Table 5). The study on the work posture characteristics by work processes in turn would provide an in-depth understanding for functional work clothes development combined with the findings about the work process categories based on the work environments featured. In addition, Figure 6 displays the comparison of the average impact levels of total work environment factors and total work posture factors of the work processes defined. To see the tendency of the average levels of total work environment factors and total work posture factors together, it is interesting to look at the similar levels within a work process. However, the processes of welding (in automobile), cutting-and-forming, painting, and

<Table 5> The classification of the work process categories of (A) automobile, (M) machine and (S) shipbuilding industries

Industry Work process category	Automobile	Machine	Shipbuilding	Industry Work process category
Work process category 1	(A) Pressing	(M) Cutting-and-forming	(S) Attachment-and-construction	Work process category 2
	(A) Welding	(M) Welding	(S) Welding	Work process category 3
	(A) Assembly	(M) Painting	(S) Grinding	
	(A) Inspection	(M) Inspection	(S) Painting	Work process category 4
Work process category Industry	Automobile	Machine	Shipbuilding	Work process category Industry

inspection (in machine) have a higher average impact level of total work posture factors than that of total work environment factors; whereas the result in the welding process (in shipbuilding) is the reverse.

To develop specialized work clothes by the work process categories classified, it is necessary to consider which work environment and work posture factors are indeed required. Work process category 1, including the steel panel pressing and auto body assembly, final inspection (in automobile) and inspection (in machine), focuses on arm movement and upper clothes bodice mobility and requires protection from the toxic fume work environment factor. It may require a long sleeve design with cuffs conformed to the wrist and reinforced with tear resistant material for the work jacket. In particular, the inspection process in the machine industry also requires high mobility for lower

body actions. So, an elastic material/sewing technique should be used for the pants.

Work process category 2, consisting of welding (in automobile), cutting-and-forming (in machine) and attachment-and-construction (in shipbuilding), is concerned with all the types of work posture bending factors defined in the study. Accordingly, suitable work clothes' elasticity, durability and protective performance from the metal fragment, fume, workplace temperature, superheat, toxic gas, and UV ray work environment factors would be required to a high degree.

Work process category 3, comprising the welding and grinding in the machine and shipbuilding industries, requires work clothes with elasticity, particularly for lateral bending mobility. However, since this work process category deals with welding and grinding devices it requires high performance of incombustibility and

heat-resistance at the same time. Thus, its work clothes should fulfil the elasticity requirement by applying a constructive clothing design, e.g. pleated or shirring details, rather than using a synthetic stretch fabric which has low heat/flame resistance. It also requires materials providing durability, abrasion resistance and performance incombustibility and heat-resistance. Considering that the metal fragment factor impact levels in this work process category were high and that metal fragments penetrating into work clothes can cause workers skin trouble, it demands special outer work clothes design for the sleeves' and pants' hems to be sealed tight.

Finally, work process category 4, including the

painting processes in the machine and shipbuilding industries, requires both waterproofing and air permeability to protect from the organic solvent factor; as well as thermal performance in winter, considering the workplace temperature factor impact levels; elasticity providing the wearer mobility for all work posture factors; and durability and abrasion resistance for the protective garments.

The results derived from this study could provide an improved clothing environment for manufacturing workers in the automobile, machine and shipbuilding industries in South Korea by suggesting guidelines for the development of specialized work clothes prototypes

Note: Impact level 1 – Very low; 2 – Low; 3 – Moderate; 4 – High; 5 – Very high

<Figure 6> Average impact levels of total work environment factors and total work posture factors in automobile, machine and shipbuilding manufacturing work processes

(design and pattern) based on the work process categories classified in this study. Moreover, the collaborative research methodology between clothing and industrial safety engineering conducted in the study will appropriately evaluate the work performance and efficiency achieved by functional work clothes at manufacturing sites. Further study will consider the workers' self assessment of the fit factors of work clothes and this may provide more insight into the development of work clothes along with the work process categories proposed. All together this will enable the achievement of the improvement of work clothes' performance and mobility, and thus ultimately the safety and efficiency of the heavy industries considered in this study.

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접수일(2012년 9월 27일),
수정일(1차 : 2012년 10월 19일),
게재확정일(2012년 10월 29일)