R. Latino-amer. em Aval. do Ciclo de Vida, Brasília, v. 2, n. 2, p. 62-84, jul./dez. 2018

Replacement of mineral oil based grease by fiberglass textile with Teflon™ as demolding agent in the bonding process: an environmental evaluation

Substituição de graxa à base de óleo mineral por fibra de vidro têxtil com Teflon™ como agente de desmoldagem no processo de dublagem: uma avaliação ambiental

La sustitución de grasa a base de aceite mineral por textiles de fibra de vidrio con teflón™ como agente de desmoldeo en el proceso de unión: una evaluación ambiental

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Abstract

Cleaner Production (CP) includes actions to prevent, minimize and recycle waste. The present study deals with the use of CP concepts in the dubbing process in a company located in the region of Porto Alegre, RS, Brazil. The process was performed in a cubic chamber, and the material used was a polyurethane adhesive. Once the adhesive has been applied onto the substrate using a spray gun, mists are formed in this chamber, causing adhesive to generate deposits on the walls of the housing. This residual adhesive deposited on the walls was removed at regular intervals of time. In order to prevent the formation of deposits on the walls and facilitate their removal, in the conventional process the walls of the chamber were coated with mineral grease, thus generating a class I (hazardous) waste. The CP actions were implemented to rule out the need to use grease. This study aimed to find the best solution for this purpose. In this sense, a product that played the same role as the grease, which is a release agent, was investigated. For this purpose, a glass fiber was tested along with Teflon™ fabric as a non-stick coating. As a result, it was *found that the time to clean the chamber was reduced and the adhesive residue generated was free from grease contamination. However, in addition to the possibility of increased reuse of the waste, the application of CP in this process has made the environment safer for workers, since they are no longer exposed to grease. In addition, Class I (hazardous) waste previously generated has changed to classified as Class II (non-hazardous) waste. In addition to reducing the costs involved, the amortization of the investment took place at around 16 days.*

Keywords: *Cleaner production. Bonding process. Grease. Fiberglass textile with Teflon™. Materials substitution. Raw material substitution.*

Resumo

Produção Mais Limpa (P+L) inclui ações para prevenir, minimizar e reciclar resíduos. O presente estudo aborda o uso de conceitos P+L no processo de dublagem em uma empresa localizada na região de Porto Alegre, RS, Brasil. O processo foi realizado numa câmara cúbica, e o material usado foi um adesivo de poliuretano. Uma vez que o adesivo foi aplicado sobre o substrato usando uma pistola de pulverização, névoas são formadas nesta câmara, levando parte adesivo gerar depósitos nas paredes do compartimento. Este adesivo residual depositado nas paredes era removido em intervalos regulares de tempo. A fim de evitar a formação de depósitos nas paredes e facilitar a sua remoção, no processo convencional, as paredes da câmara eram revestidas com massa lubrificante de óleo mineral (graxa), gerando assim um resíduo classificado como classe I (perigoso). As ações de P+L foram implementadas para descartar a necessidade de uso de graxa. Este estudo teve como objetivo encontrar a melhor solução para esse fim. Neste sentido, foi investigado um produto que desempenhou o mesmo papel da graxa, ou seja, um agente de liberação. Foi testada para este fim, uma fibra de vidro juntamente com tecido Teflon™ como revestimento antiaderente. Como resultados, verificou-se que o tempo para limpar a câmara se reduziu e o resíduo do adesivo gerado apresentou-se livre de contaminação por graxa. Contudo, além da possibilidade de reutilização acrescida ao resíduo, a aplicação de P+L neste processo tornou o ambiente mais seguro aos trabalhadores, pois eles deixaram de estar expostos à graxa. Além disso, o resíduo de classe I (perigosos) passou a ser classificado como resíduo classe II (não perigoso). Além da redução dos custos envolvidos, a amortização do investimento se efetivou em torno de16 dias.

Palavras-chave: *Produção mais limpa. Processo de dublagem. Graxa. Fibra de vidro têxtil, com Teflon™. Substituição de materiais. Substituição de matérias-primas.*

Resumen

Producción más limpia (P + L) incluye acciones para prevenir, minimizar y reciclar residuos. El presente estudio aborda el uso de conceptos P + L en el proceso de doblaje en una empresa ubicada en la región de Porto Alegre, RS, Brasil. El proceso se realizó en una cámara cúbica, y el material utilizado fue un adhesivo de poliuretano. Una vez que el adhesivo se ha aplicado sobre el sustrato usando una pistola de pulverización, las nieblas se forman en esta cámara, llevando parte adhesiva para generar depósitos en las paredes del compartimiento. Este adhesivo residual depositado en las paredes se retira a intervalos regulares de tiempo. Con el fin de evitar la formación de depósitos en las paredes y facilitar su remoción, en el proceso convencional, las paredes de la cámara estaban revestidas con grasa de aceite mineral (grasa), generando así un residuo clasificado como clase I (peligroso). Las acciones de P + L fueron implementadas para descartar la necesidad de uso de grasa. Este estudio tuvo como objetivo encontrar la mejor solución para ese fin. En este sentido, se investigó un producto que desempeñó el mismo papel de la grasa, es decir, un agente de liberación. Se ha probado para ello una fibra de vidrio junto con tejido Teflon™ como revestimiento antiadherente. Como resultados, se verificó que el tiempo para limpiar la cámara se redujo y el residuo del adhesivo generado se presentó libre de contaminación por grasa. Sin embargo, además de la posibilidad de reutilización más elevada del residuo, la aplicación de PML en este proceso ha hecho que el medio ambiente sea más seguro para los trabajadores, ya que dejan de estar expuestos a la grasa. Además, el residuo de clase I (peligrosos) se clasificó como residuo clase II (no peligroso). Además de la reducción de los costos involucrados, la amortización de la inversión se efectuó en torno a los 16 días.

Palabras clave: *Producción más limpia. Proceso de doblaje. Grasa. Fibra de vidrio textil con Teflon ™. Sustitución de materiales. Sustitución de materias primas.*

1. Introduction

With new technologies emerging at a fast pace, companies have acknowledged the fact that they have to streamline processes if they want to improve product quality and increase productivity. However, what many managers fail to perceive is that environmental management tools such as cleaner production (CP) may be the best resource for that end, reducing costs and averting significant environmental impacts.

For Bai et al. (2015), CP is a preemptive environmental strategy adopted in product, process, and service improvement. The aim is to reduce negative impacts to human and environmental health. In this context, the authors claim that CP improves the environmental performance of companies. In addition, Grutter and Egler (2003) pointed to the financial benefits to be reaped with the initiative.

Zhang and Wang (2015) show that maintaining a cleaner environment has become a global concern. However, if on the one hand we are faced with alarming pollution levels inherent to industrial growth, on the other we are now witnessing the efforts to merge industrial progress and clean technologies. It is from this perspective that Severo et al. (2015) point to the links between globalization, industrial development, and pollution, highlighting the need for mitigating negative environmental impacts. Such demands may be met adopting CP methods, as highlighted by Júnior et al. (2013) when claiming that the most efficient approach to environmental impact mitigation includes the implementation of clean technologies.

According to Buccelli and Costa Neto (2013), industries today are required to implement strategies directed to the continuous improvement of quality and efficiency of products and services alike, reducing waste and the consumption of raw materials. Severo et al. (2013) expand on that, adding that this is precisely the path to increasing competitiveness and improving organizational performance. Zeng et al. (2010) also believe that companies have become aware that CP is instrumental in becoming more sustainable, which eventually translates as greater competitive edge.

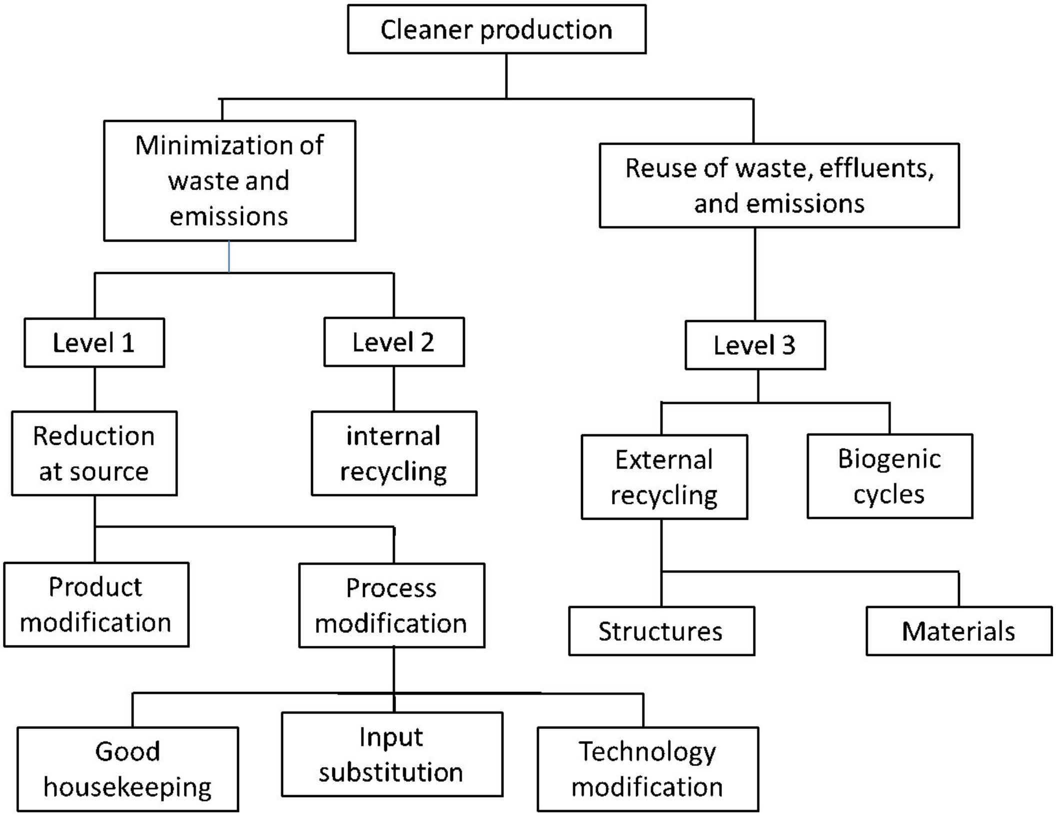
CP is increasingly adopted not only by enterprises of the manufacturing sector, but also by planning, design, and operation organizations. However, the evolution of environmental systems requires an appropriate monitoring approach (KLEMES et al., 2012).

Another interesting point is the possibility to bring down waste treatment and disposal costs by adopting a waste prevention or reduction system

(SEIFFERT, 2011). In this sense, Kurdve et al. (2015) point to the direct correlation between the efficiency and the costs of such initiatives. For the authors, mapping waste generation streams is an important tool when trying to identify opportunities for improvement, in reducing or even eliminating waste from processes.

In this context, CP initiatives may be the pathway for the notions discussed in the literature to take shape in practice. According to Centro Nacional de Tecnologias Limpas (2003), CP actions are grouped under three levels (Figure 1). Level 1 actions are the most important, since their objective is to minimize waste generation at source.

Figure 1: Flowchart showing CP levels and respective practical actions.



Source: Centro Nacional de Tecnologias Limpas (2003).

In the CP actions is included production processes optimization to reduce waste generation through small adjustments to the operating model or even through the acquisition of new technologies, whether simple or complex. (NORMAL; LEMOS; MELLO, 2008). Severo, Guimarães and Dorion (2017) state that CP methods, as well as Environmental Management practices aim at the efficiency of the production process, the use of inputs and the non-generation of waste. According to Severo, Guimarães and Dorion (2017), such tools can contribute to the sustainable innovation of products, due to the rational use of natural resources.

1.1. Unidade de estudo Study Cell

The present study evaluated the bonding process adopted in a company in the Greater Porto Alegre region, state of Rio Grande do Sul (RS), Brazil.

It is important to emphasize that this research was not intended to implement the CP program, but to use its concept based on actions of level 1 and, thus, to eliminate or reduce the generation of wastes in the sponge bonding process household use. The first stage was the diagnosis of the process. This stage contributed to the identification of the points in the production chain for which mitigation and impact minimization actions were proposed. The processes diagnosis also assists in the quantification of residues. (POPI; JESUS; KULAY, 2016; SCHUEROFF, 2013).

In the process, a polyurethane (PU) adhesive is used as glue, in addition to an isocyanate-polyol polymer and specific additives pre-incorporated to polyol (VILAR, 1998). The process consists in gluing two substrates by spraying a PU adhesive on the surface of one of them using a specific gun, which sprays the two components (polyol and isocyanate) simultaneously. The reaction is mediated by collision. This operation is carried out in a chamber equipped with a gas scrubber that removes the adhesive suspended in the air. However, the gas scrubber does not prevent part of the suspended adhesive from forming a film on the surface of the equipment. Since this adhesive cures fast, the film

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formed may influence the process and has to be removed at specific time intervals, generating large amounts of waste. In order to prevent adhesion to the chamber's walls and to facilitate the removal of films formed, the inside surfaces of the chamber are coated with a layer of grease that, according to the manufacturer, is produced using mineral oil formed by a complex mixture of mainly paraffinic hydrocarbons, adhesive additives, and hydrated lime (IPIRANGA, 2012).

However, this grease contaminates the polymer waste, as shown in Figure 2. This process is carried out in a cubic chamber, whose bottom side is open, along which a conveyor belt transports the substrate to receive the adhesive layer (Figure 3). A collector below the opening is coated using the same grease used on the walls, since part of the adhesive does not fall on the substrate, sticking to the collector and the walls. At the top of the chamber, the gun applies the adhesive. In order for the operation to be evenly carried out, the moving gun is runs perpendicularly to the conveyor. No adhesive is deposited on the conveyor, since its width is identical to that of the substrate.

Figure 2: Polyurethane adhesive and inner surface of the chamber dirty with grease.

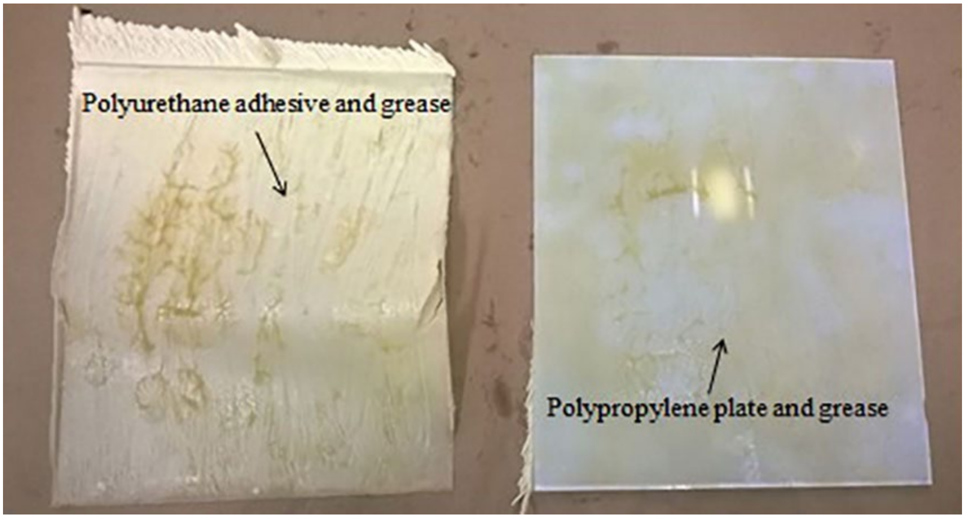
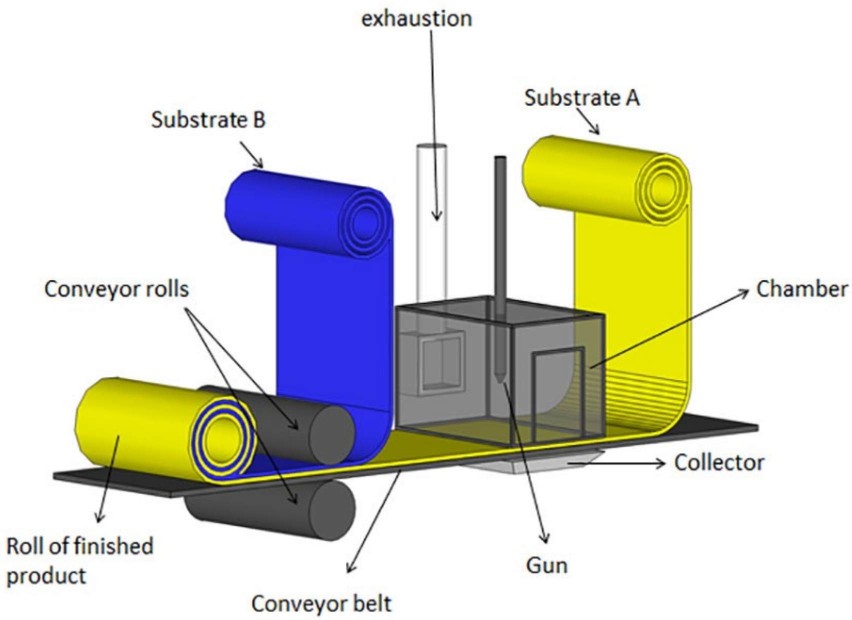


Figure 3: Diagram of the bonding process.



Considering that the grease is used as an adjuvant in the bonding process and that it contaminates the PU adhesive waste, the main objective of the present study was to find an alternative to grease in this process. So, apart from producing a class II A waste (non-dangerous, but reactive depending on the environmental conditions) according to NBR 10004 (BRASIL, 2004), instead of a class I waste (dangerous), the waste can be reused. In order to evaluate the feasibility of changing the bonding process, an economic and environmental assessment was carried out.

On average, the company generates 10 m3 of PU waste contaminated with grease daily. In the search for an economically and environmentally plausible alternative to solve the problem, we investigated CP actions.

The main role of this grease is to act as release agent. For this reason, we searched for other materials that could fit this purpose without contaminating the polymer waste.

When inspecting processes in the company, we realized that another operation used fiberglass fabric coated in Teflon™ as non-stick coating (Figure 4). One of the sides of the material is covered with adhesive, and is sold as large rolls, which could be used to completely cover all surfaces of the chamber easily and without having to slice the material.

Figure 4: Fiberglass fabric covered with Teflon™

Source: Varoflon (2015).

Polytetrafluoroethylene (PTFE), whose commercial name is Teflon™, is patented by the company DuPont. It is an inert material that does not react with other chemical substances, except in special situations, and therefore its toxicity is essentially zero (MORASSI, 2015). It is commonly used in kitchenware, since its low attrition coefficient prevents foods from sticking to pans (FELTRE, 2005).

For Mano and Mendes (1999), PTFE has good heat resistance, which is an important property considering that the reaction between polyol and isocyanate is exothermic.

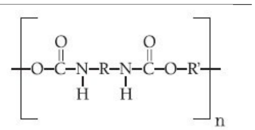
Based on the properties of Teflon™, we decided to test the fiberglass fabric coated with Teflon™. With that in mind, we carried out a laboratory test and an assay during the bonding process in order to assess the possibility to use the material. It was after these tests that the material was installed on the bonding chamber.

2. Materials and methods

2.1. Materials

The materials used in the present study are shown in Table 1.

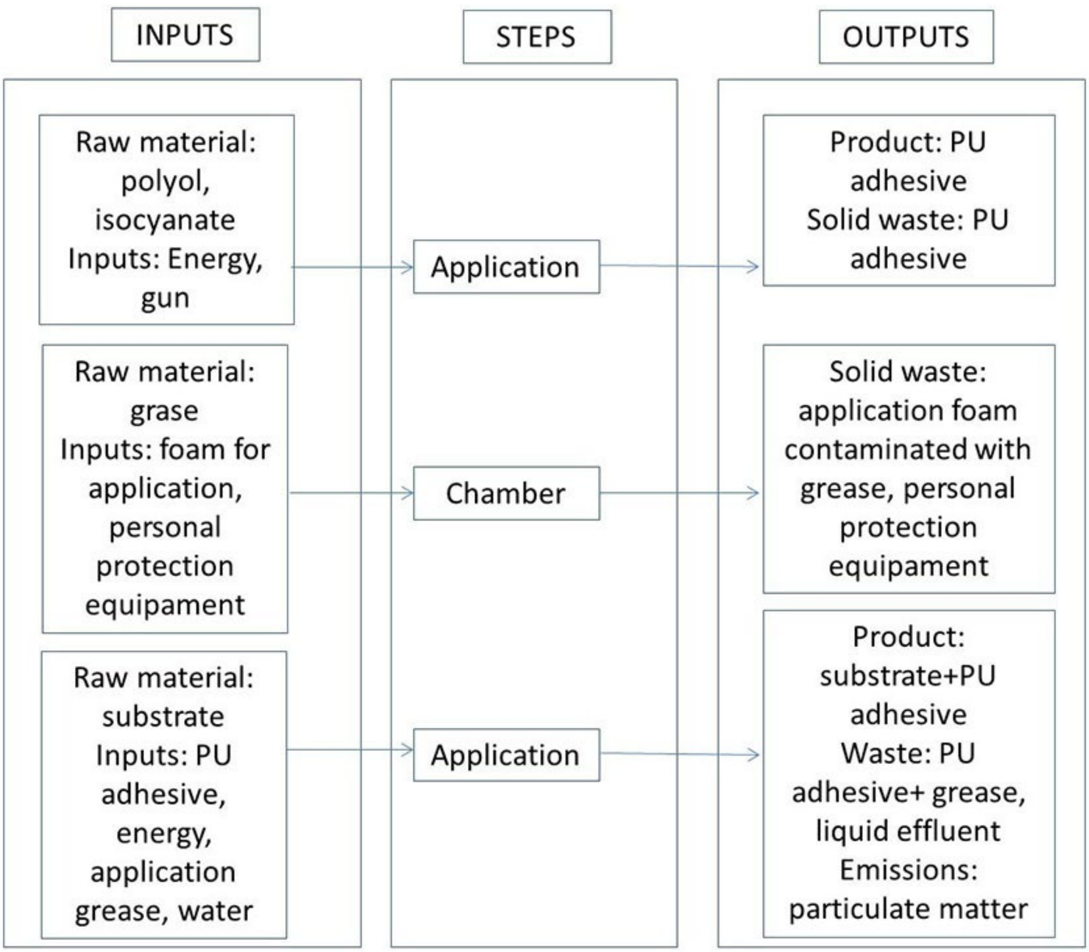
Table 1: Characteristics of the materials.

Material	Fiberglass fabric + Teflon™	Mineral oil grease	PU adhesive
Characteristics	Heat resistance	May cause skin rash	Used as adhesive
	Low attrition coefficient	Mild inflammability	When considered a waste, it is classified as Class II A waste – inert
	One of the sides has an adhesive layer	Creamy at room temperature	Thermostable polymer
	Sold in rolls	Insoluble in water	Obtained with a reaction between polyol, isocyanate, and additives
	Inert	Dangerous product	Fast cure <15 min
Chemical composition	$SiO_2 + -(F_2C = CF_2)-$	Mineral oil grease	

2.2. Block flowchart of the bonding process

Figure 5 illustrates the block flowchart of the original process, showing the use of grease and the waste generated.

Figure 5: Block diagram of the original bonding process (using grease as release agent)



2.3. Environmental Aspects and Impacts

After the survey of environmental aspects and impacts of the processes with the use of grease as a release agent and the use of fiberglass fabric with Teflon ™ as a release agent, impacts on soil, water, air, natural resources and Cheers. The scale used in the classification of environmental impacts varies from 1 to 5, as shown in table 2.

Table 2: Evaluation Scale

1	Low impact
2	Medium low impact
3	Medium impact
4	Medium high impact
5	High impact

Source: Adapted from Potrich, Teixeira and Finotti (2007)

This methodology was adapted from Potrich, Teixeira and Finotti (2007) that used to evaluate the environmental impacts of the automotive paint process and the methodology used by Silva and Moraes (2012) used to evaluate the environmental impacts of a plastic industry. Both authors were based on the Leopold matrix that seeks to associate environmental impacts with human actions (SANCHEZ, 2011).

An array consists of two lists arranged in the form of rows and columns. One of them presents the actions that make up the enterprise or a process and in the other the elements of the environmental system in order to identify the possible interactions between them. (SANCHEZ, 2011)

2.4. Method

Suitability of materials was examined using a preliminary laboratory test, a pilot test during production, and an industrial scale test (developed based on the results of the two previous tests).

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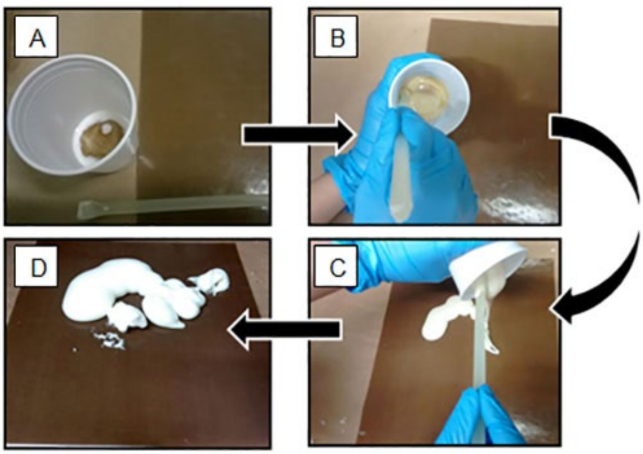
2.4.1. Laboratory test

A small amount of PU adhesive was prepared with the same raw materials used in production (polyol and isocyanate). The materials were weighed in a polystyrene vial and vigorously mixed for 10 s in order to promote the reaction. Next, the mixture was poured on a 30 cm x 30 cm sample of the fiberglass fabric + Teflon™ to assess the degree of difficulty to remove the product. The procedure was adopted because it was not possible to prepare the production mixture using the materials available in the laboratory.

Figure 6: Laboratory test



A: weighing of raw materials (polyol and isocyanate); B: mixture; C: pouring of mixture on the fiberglass fabric + Teflon™; D: final product on Teflon™.

2.4.2. Industrial scale test and implementation

Two small samples of fiberglass fabric + Teflon™ were collected inside strategic sites in the chamber: one site where waste is deposited in large amounts, one where deposition was small during a 3-h operation period of the bonding chamber. The site chosen to receive a large amount of adhesive was the collector, since it lies opposite the gun and receives larger amounts of PU adhesive. Concerning the deposition of small amounts, it occurs on the chamber walls, since the PU adhesive is sprayed using a gun, favoring the formation of mists that deposit on the walls, forming thin adhesive films.

3. Results and discussion

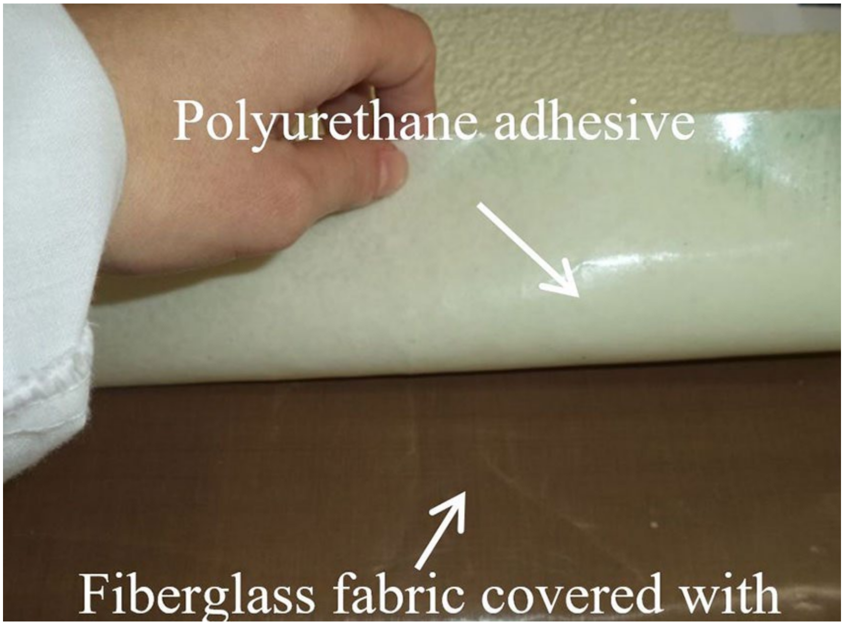
3.1. Evaluation of the removal of PU adhesive on the fiberglass fabric + Teflon™

The laboratory test afforded to gain an insight into the feasibility of installing a fiberglass fabric + Teflon™ in the bonding chamber, since the results were acceptable. In other words, it was extremely easy to remove the PU adhesive, though it also adhered to the walls.

Figures 7 and 8 illustrate the test carried out during the process, in two stages: deposition of large and of small amounts of PU adhesive.

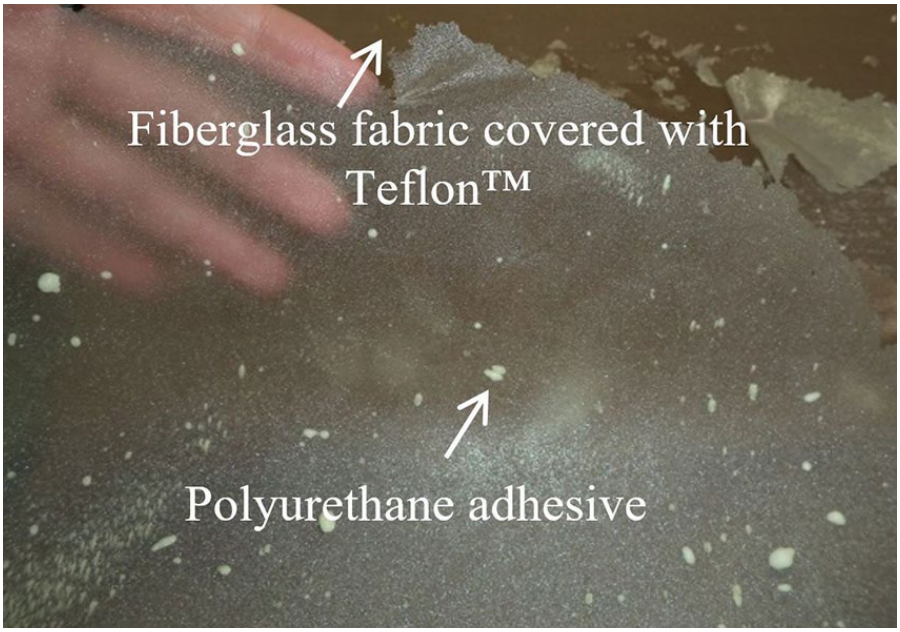
Figure 7 shows the deposition of PU adhesive, since Teflon™ was installed on the collector, which is placed opposite the gun and therefore receives larger amounts of PU adhesive.

Figure 7: Large amount of waste deposited on Teflon™.



The PU adhesive is applied using a gun, favoring the formation of mists that promote the generation of very thin films in some spots in the chamber (Figure 8).

Figure 8: Small amount of waste on Teflon™.



Based on the positive results obtained, the grease was replaced by Teflon™ fiberglass fabric.

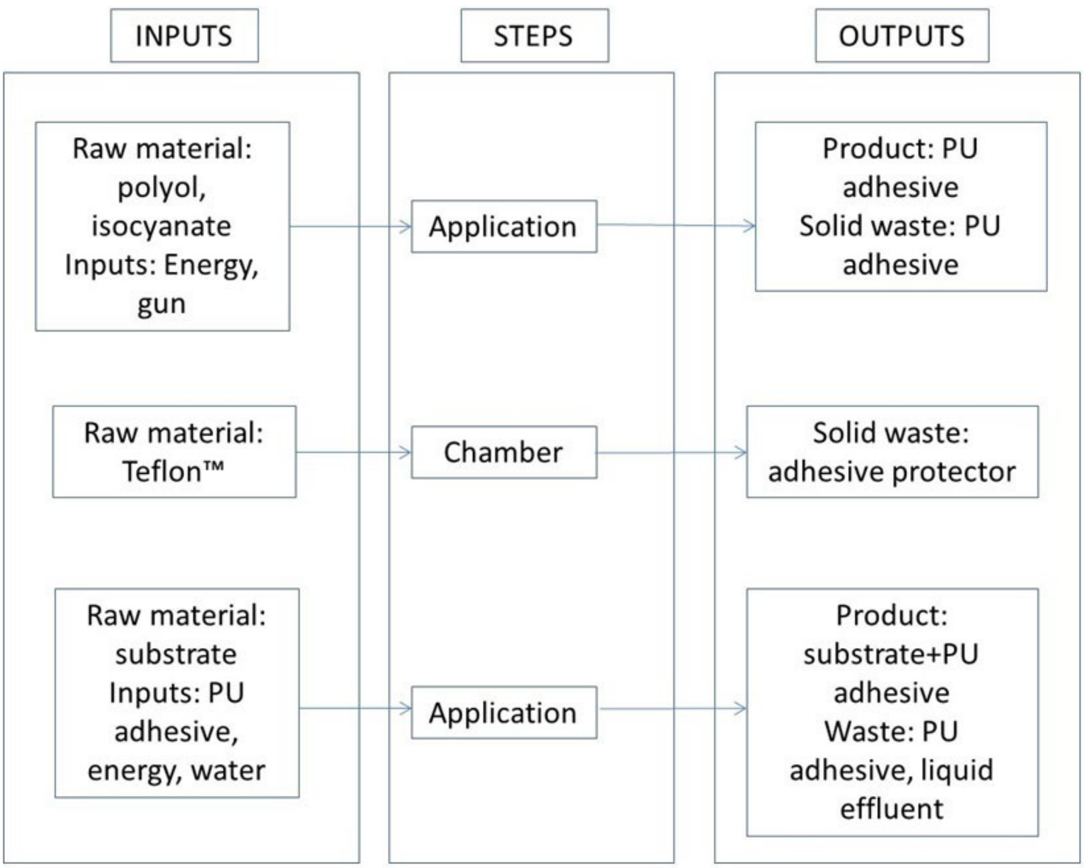
Although, grease layers had been applied on the chamber walls and on the collector, it was not possible to adhere the material to be tested, even after extensive cleaning of surfaces. The removable walls are made of polypropylene, so we decided to replace the old plates with new ones, both in the collector and in the chamber.

After replacement, the material to be tested could be glued. This process was carried out taking a few precautions in order to prevent the formation of air bubbles and joints, since these may break or make the material peel.

The operators were instructed on the importance of the new system, the benefits it would bring, the necessary care and the new way of disposing the waste removed from the chamber's walls.

After implementation, a block diagram was prepared illustrating the use of the new release agent shown in Figure 9.

Figure 9: Block diagram of the bonding process using Teflon™ as release agent.



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3.2. Environmental evaluation of the implementation of the technique

Tables 3 and 4 show the results obtained in the quantification of impacts for both processes which shows the relationship between the causes (aspects) and the consequences (impacts).

Table 3: Adaptation of the Leopold's matrix for the use of grease as a release agent

		Impact					
		Physical				Anthropic	
		Soil	Water	Air	Natural Resources		
		Soil contamination	Contamination of water resources	Air pollution	Consumption of renewable or non-renewable natural resources	Health	**Partial Totals**
Aspect	Polyol consumption	5	5	-	3	5	18
	MDI consumption	5	5	3	3	5	21
	Water consumption	-	-	-	3	-	3
	Electric power consumption	-	-	-	3	-	3
	Generation of atmospheric emissions, particulate matter, flammable vapors, gases	2	2	5	-	5	14
	Generation of liquid effluents	5	5	-	-	5	15
	Grease consumption	5	5	4	3	5	22
	Generation of PU contaminated with grease	5	5	4	3	5	22
	Generation of plastic waste from grease packaging	5	5	4	4	5	23
						Total	141

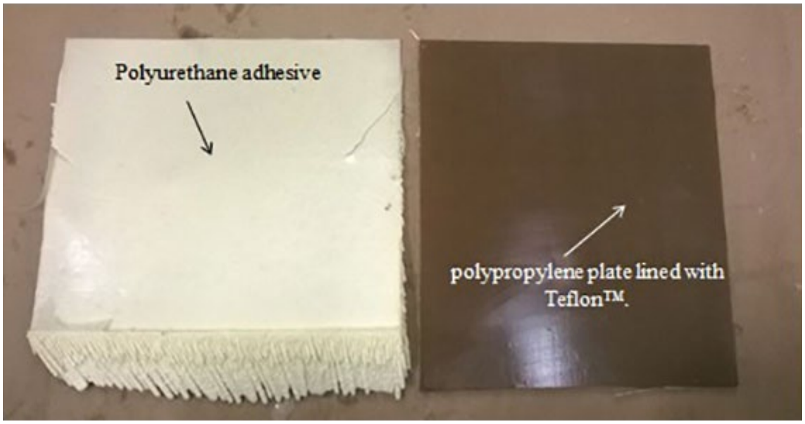
Table 4: Adaptation of the Leopold's Matrix for the use of fiberglass fabric + Teflon™ as a release agent

		Impact					
		Physical				Anthropic	
		Soil	Water	Air	Natural Resources		
		Soil contamination	Contamination of water resources	Air pollution	Consumption of renewable or non-renewable natural resources	Health	**Partial Totals**
Aspect	Polyol consumption	5	5	-	3	5	18
	MDI consumption	5	5	3	3	5	21
	Water consumption	-	-	-	3	-	3
	Electric power consumption	-	-	-	3	-	3
	Generation of atmospheric emissions, particulate matter, flammable vapors, gases	2	2	5	-	5	14
	Generation of liquid effluents	5	5	-	-	5	15
	Generation of polyurethane waste without grease	2	2	2	-	1	7
						Total	81

Taking into account that the criterion score was increasing (1 to 5), from which 1 was the lowest impact and 5 was the highest, the larger the sum product, the greater the impact. Therefore, it is possible to observe that the process that uses the grease as a release agent presents a 42.5% greater impact in relation to the process that stopped using the grease and started to use the fiberglass fabric + Teflon™ as a release agent.

In addition, an important benefit was the transformation of a hazardous waste into a non-hazardous one, since the PU waste is not contaminated, as shown in Figure 10.

Figure 10: PU adhesive and polypropylene plate lined with Teflon™.



Following on-the-spot monitoring and data collection, Tables 5 and 6 show the data used in the economic assessment of release agents. This information covers the year 2014.

Table 5: Information about the use of grease as release agent (considering US$ 1 = R$3.80)

Cost	US$ 1.64/kg
Monthly consumption	200 kg
Monthly generation of contaminated waste	≈ 10 m^3
Class I waste disposal costs	US$ 30.00/m^3
Total time to clean the chamber (with grease)	≈1 h

Table 6: Information about the use of fiberglass fabric bonded with Teflon™ as release agent

Cost of fiberglass-Teflon™ fabric	US$ 32.36/m^2
Cost of polypropylene board	US$ 4.27/m^2
Chamber area	19.40m^2
Total time to clean the chamber (without grease)	≈15 min
Class II waste disposal costs	US$ 64.76/t of waste

The data in Table 5 afforded to calculate the direct and indirect costs associated with the use of grease. Direct costs are associated with purchase, while indirect costs include the expenditures with disposal of class I waste (hazardous). The data show that 200 kg of grease are used monthly, at US$1.64 one kilo, corresponding to an expenditure of US$328.94 a month. The cost associated with disposal is US$30.00 per cubic meter. Since 10 m3 contaminated polymer waste are generated a month, the cost is US$300.00 a month. Total direct monthly costs of using grease as release agent is US$628.00 approximately.

The data listed in Table 6 were used to calculate the costs of the new proposal. The fiberglass+Teflon™ fabric is sold for US$32.36 per m2. Since the chamber area is 19.40 m2, the total cost of implementation was US$627.89. Nevertheless, new polypropylene were required, requiring further US$82.96 and raising the total cost to US$710.90.

The life cycle of the fiberglass+Teflon™ fabric is being investigated, though it is possible to say that it may be of at least 5 months, increasing benefits of the system.

Since it was not necessary to replace the fiberglass+Teflon™ fabric or the polypropylene plates during this period, the monthly costs of the new proposal will be due to disposal of the waste in a class II A landfill only, that is, US$64.76 per metric ton of the waste generated. The 10 m3 of waste generated account for approximately 3 metric tons, which means that the monthly disposal costs are US$194.28. The implementation costs of the new proposal was divided across the five months during which it as not necessary to replace any of the materials used.

Tables 5 and 6 reveal that the sum invested in the new proposal would return in 16 days.

With this improvement, only 15 min were necessary to remove the adhesive, with no grease, which means an improvement in quality of life of workers, since they do not need to handle grease, which may cause skin rash (IPIRANGA, 2012).

4. Conclusions

The present study shows that it is possible to replace grease by fiberglas+Teflon™ fabric, reducing cleaning time and eliminating the use of grease in the bonding chamber and preventing contamination of the adhesive waste generated. This process improvement required an investment of US$710.90, which, according to the data obtained, may pay itself in 16 days. In other words, the system means savings as of the first 15 days of implementation. Additionally, as long as the materials do not need to be replaced, both environmental and economic benefits will increase.

Therefore, other advantages include the fact that 10 m3 of dangerous waste are not generated, and consequently, the possibility of reusing the class II waste (non-inert) formed. In this case, if it can be used as raw material in other processes, even at low proportions, the requirements concerning new raw materials are lower, decreasing impacts even more.

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