Cutting processes in shipbuilding–a case study

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Cutting processes in shipbuilding—a case study

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ABSTRACT: In order to improve the production in the shipbuilding industry, the first phases of construction have a significant role on the production process, namely the steel cutting. This steel process stage represents a key factor of the optimization of the production process, because the implementation of new and more accurate technologies can generate an important reduction of the re-work due to the steel deformation and other consequences. The study of the various cutting technologies is essential to prove the advantages of the newest and more advanced cutting processes, such as the plasma, the laser or the water abrasive jet. The present paper aims to present a case study of two different cutting processes, oxy-fuel and plasma cutting. Although all the cutting parameters were not studied such as consumables rates for example, this study concerns the practical situations during the cutting processes on the steel process shop, i.e. speed of the cutting process, man-hours needed or problems that can occur during the cutting process.

1 INTRODUCTION

Today the cutting processes implemented in the construction shipyard are a key factor in the important process of turning the shipyard into a more competitive company (Cahill *et al*. 2000). The developments of newer and better cutting techniques and technologies allow also the implementation of new construction concepts and sequences (Guluwita *et al*. 2014).

Although the welding activities are the responsible for the bigger part of the re-work due to the thermal deformation, the cutting activities have also an important weight in the amount of this post activity necessary. So, not only the speed of cutting, but also the cutting quality are an important factor in which the new cutting processes can present significant cost reduction on the production process. Till this day the main cutting technology applied in the ship construction industry was, and continue to be, the oxy-fuel cutting. However new developments on the past few decades have turned possible the implementation in the shipbuilding industry of new technologies, like the plasma cutting, the laser cutting and the waterjet cutting.

In order to study the characteristics of the various cutting processes there are today at the disposable various published data, either studies or manufacturers product information, however it is very important to, as ever as possible, take the data from the real cases, in order to comprehend parallel events that are attached to the cutting process itself and can condition the activity. Hence, this paper portrays and process the data collected from some cutting activities during a ship construction in the *WestSea Shipyards*, in Portugal.

2 DATA COLLECTION

2.1 *Cutting process flow*

The data presented in the next chapters, although its differences, such as speeds and technologies applied, prove that both process sequences are similar and can be generically characterized by a flow chart scheme, divided in twelve stages, as presented in the Figure 1.

The present study is restricted to the analysis of the stages comprehended between the cutting preparation stage and the transport of the processed steel plates out of the cutting table.

The cutting technology applied in the process is key not only to define the above referred stages, here analyzed, but also to the beveling and grinding stage of the piece. The quality allowed by the plasma cutting technology grant much smaller times in the grinding activity stage, in a factor of three to one (Hypertherm 2016), thus improving the process production, both total process time and man-hours.

Need to stress also the importance of the cutting technology on the post work manual beveling activities. This secondary work is needed in situations of oxy-fuel cutting machines that do not allow beveling of the steel piece, increasing drastically the man-hours needed to accomplish the final

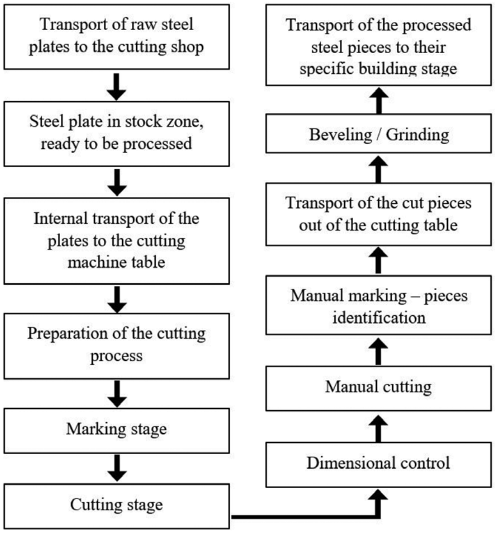

Figure 1. Generic cutting process flow chart.

cutting process with the expected cutting characteristics and quality.

2.2 *Oxy-fuel cutting*

The oxy-fuel cutting process data was taken from the intermediate stage of the panel line, after the submerged arc welding of the base steel plates that forms the panel, and before the positioning and welding of the longitudinal stiffeners (Oliveira & Gordo 2017).

The cutting equipment consists on a cutting head gantry system (TELEREX-TX B1500 model, ESAB brand). The system has a main cutting torch (Figure 2) and two secondary torch for beveling works, and the possible area of cut that comprehends 17.9 m length and 13.6 m width. The minimum plate thickness that this machine can process is 5 mm.

2.3 *Plasma cutting*

Recently *WestSea Shipyards* acquired a new plasma cutting machine that turned to be an important unit in the construction flow process. This equipment is located in a specific cutting shop in the yard. It consists on a single cutting head that can do either vertical cuts or beveling works. The working table can accommodate two steel plates longitudinally, allowing the cutting activity in one side and the simultaneous triage in the other.

Although the two studied cutting activities do not serve the same goal, i.e., one is inserted in the panel line and the other cut small and medium steel pieces, one can compare the cutting activity itself, its speeds and its singularities, requirements and other characteristics.

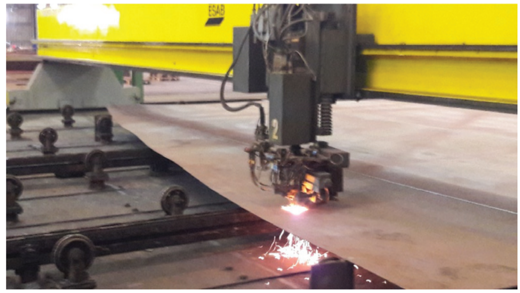

Figure 2. Oxy-fuel cutting.

3 DATA PROCESSMENT

3.1 *Oxy-fuel and plasma specific characteristics*

Before present and studied the specific data collected, like speed and general time activities, it is important to list here some singularities of each one of the cutting technologies implemented on the shipyard, mainly the process preparation, because it is obviously different from on cutting technology to the other and also because they belong to different stages of the construction, like said before.

The oxy-fuel cutting process present the listed characteristics:

- It is incorporated in the panel line flow, and because of that the possible bottlenecks in either previous stages or next stages of this production line present serious contingencies to the oxy-fuel cutting, e.g. reduction of the working force available to perform the cutting activity and, consequently increase the needed time to accomplish the work.
- The quite old age of the panel line oxy-fuel cutting gantry has visible consequences, like the fact that the CNC information for the process is physically transported to the machine, and sometimes the interruption of the process leads to “memory loss” and some work, like the steel marking must be repeated;
- Considering that the horizontal transport of the panel into the cutting area is not a preparation activity, other activities can be identified as that. Stabilize the panel with steels chocks in each corner of the panel is a job that can be performed either by one or two workers, the CNC information introduction in the cutting machine computer is a one-man activity, such like the monitoring of the process (both marking and cutting activities);

- The large dimensions to be cut in this panel line stage make important the possibility of interruption of the cutting process, because it can happen that the work to perform is not possible to finish during the work shift.

The plasma cutting have other characteristics:

- Although the plasma cutting gantry system only presents one cutting head with only one torch, this torch has a very wide movement range possibilities, so it can also perform beveling cutting works;
- The CNC nesting files are loaded in the machine's computer trough the internal informatics share system. However, some problems were detected, like the fact of the requirement of conversion of a LANTEK made file to a specific CNC file extension compatible with the plasma cutting computer, and, sometimes, conversion errors occur, blocking the cutting work execution;
- The cutting operation is performed by two works, one introducing the CNC files in the cutting machine computer and also doing the monitoring of the cutting operation. Other worker is responsible for the triage activity of the previously cut pieces and also performs the steel plates transportation for the cutting table, with the aid of the shop's gantry cranes;
- Although it is an air exposed plasma cutting process, the fumes resulting from the plasma cutting are exhausted under the table from one side of the cutting table, hence decreasing the health and safety risks.

3.2 *Data presentation—Oxy-fuel cutting speed*

The process data of each cutting technology were processed as function of the plate thickness and cutting lengths.

The oxy-fuel cutting process, incorporated in the panel line production, was studied only as function of the length, since all the panels monitored were formed of small thickness steel plates (5 mm and 6.5 mm).

Before the cutting activity itself there is the panel's marking, with propane as the main consumable. The linear regression obtained through a set of observations is shown the Figure 3:

The linear regression presented in the Figure 3 is given by:

$$T_m = 0.08\ L_m + 23.00 \qquad (1)$$

where T_m stands for the marking time, in *min*, and L_m is the marking length, in *m*.

Hence, the linear regression of the marking gives us a marking speed of approximately 6.0 m/min, and it is important to stress that this times, and respective estimated velocity, are related to the all marking process, i.e., it also includes the marking head movement to the various locations without being actually marking.

Through careful observation and measurements, the authors had obtained the speed of the marking action itself, being approximately 6.8 m/min. So, we can easily conclude that around 12% of the marking process time corresponds to the marking torch movements without being marking.

The data collected of the oxy-fuel cutting process, show in the Figure 4, allows to build the followed linear regression:

$$T_{of} = 3.42\ L_c \qquad (2)$$

where T_{of} stands for the oxy-fuel cutting time, in *min*, and L_c is the cutting length, in *m*.

Appling the same analysis type to the cutting process, we take a process cutting speed of 0.31 m/min, and the oxi-fuel cutting itself present a speed of 0.41 m/min. Hence, 25% of the time is due to procedures other than cutting itself, e.g. movement of the cutting head and the pre-heat of the steel plate.

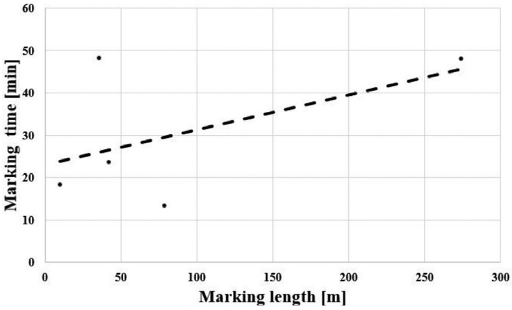

Figure 3. Marking time vs marking length.

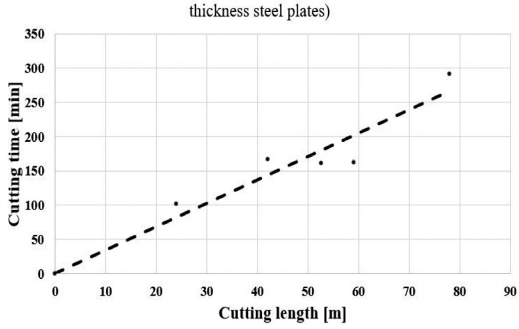

Figure 4. Oxy-fuel cutting vs cutting length.

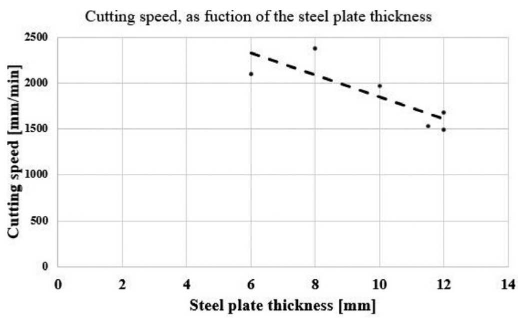

Figure 5. Plasma cutting vs steel plate thickness.

3.3 *Data presentation—plasma cutting speed*

The process of plasma cutting as also monitored. The work followed was diversified in various steel plate thickness, allowing to estimate the plasma cutting speed as function of the thickness, as seen in the Figure 5:

Hence, is easy to obtain a linear parametric equation in order to estimate the cutting speed as function of the thickness:

$$V_p = -118.8\,t + 3037 \quad (3)$$

where V_p stands for the plasma cutting speed, in *mm/min*, and t stands for the thickness of the steel plate, in *mm*.

As it happens for the oxy-fuel cut process, the cutting speed presented above also includes activities other than the cutting itself, like movements of the cutting head without being actually cutting, although with the important difference that this technology does not require pre-heating, at least for mild steel. Because it does not require the pre-heating stage, the time "lost" in activities other than cutting is not function of the plate thickness, hence this "lost" times depend purely of the efficiency of the nesting.

3.4 *Other characteristics of the cutting processes*

Due to the facts that both cutting technologies do not belong to the same block construction stage, there are many processes times, e.g. preparation time, that are not possible to compare with each other. However, it is important to present here some specific times of the cutting processes studied.

Relatively to the oxy-fuel cutting, with the collected data it is possible to analyze the time for work preparation, for dimensional cutting control and for the manual marking:

- The work preparation consists mainly on the CNC file loading in the cutting machine computer. This stage is sometimes done with two workers, one more experienced and one apprentice worker, in order to perform a very important politic in the shipbuilding industry, that is passing the knowledges to a newer working generation. This stage is independent any cutting parameter and is approximately done in half an hour;
- The dimensional control, post cut, is a very important stage of the cutting process because it substantially decreases the possibility of bigger problems along the block production. The theoretical expected dimension values are confirmed with the aim of two workers, measuring a set of dimensions of the cut panel. Although this stage is depended of the panel area, it is always around 8–10 minutes;
- As said before, this gantry cutting system do not perform the marking of text, such as the notations of the reinforcements hereafter distributed upon the panel plates. Hence, although the system marks the position of the stiffeners, the identification of that stiffeners is manually performed. One worker, with the guidance of the technical papers, manually mark the stiffeners identification in around 5 minutes, obviously as function of the complexity of the panel and number of stiffeners.

So, the oxy-fuel cutting process is constituted of various stages, each one of them fundamental for a correct quality work. In Figure 6 is presented a pie chart of one panel cutting process example that illustrate the time division of the various stages of the complete process.

The previous pie chart example is from an 87 m^2 area panel, 5 mm thickness, 274 m marking length and 78 m cutting length. Other examples cutting process examples will differ mainly in the percentage

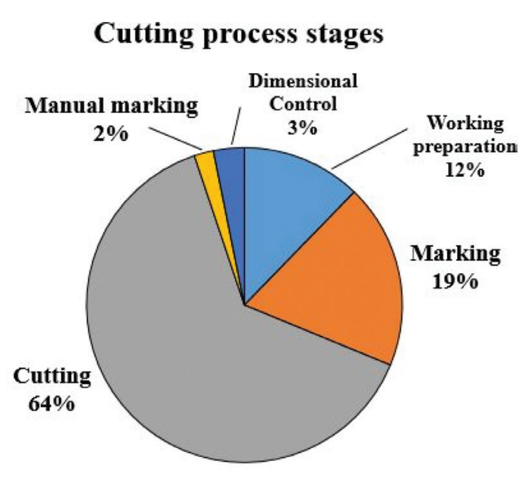

Figure 6. Time percentages of oxy-fuel cutting process stages.

of cutting time and marking time, according with the previous analysis made in the chapter III B.

In the same way, plasma cutting process also presents particular specificities that should not be omitted in the cutting process analysis. Although some stages are also present in the oxy-fuel cutting process, like the preparation work, their times periods are different because of the significantly newer cutting equipment.

- The work preparation is similar to that performed in the oxy-fuel cut, i.e., load the CNC files and localize the origin point and position of the plate to be cut. Although it is also not a specific time, this stage takes approximately 10 minutes. The smaller time, when compared to the oxy-fuel cut in the panel line, is due to the significantly new equipment and respective computer software.
- The dimensional control in this plasma cutting process has not a specific set of instructions and it is done depending on the complexity of the piece and also depending on the worker monitoring the cutting job. It can be made at the same time that the cut is being performed or it can be done in when the cutting stage is complete, in 5 to 10 minutes.
- In the plasma cutting shop, parallel to the cutting it is done a triage work in previously cut pieces. This work can be divided in the manual oxy-cut of some bridges strategically left during the plasma cutting, which obviously depends on the number and complexity of the pieces and can reach up to 15 minutes; the manual marking of some standardized notations of the pieces that were not included in the nesting file, that takes around 5 minutes; and, finally, the transportation of the cut pieces to their correct location, also depending on the sizes and number of pieces, taking up to half an hour, in order to be posteriorly transported to other shipyard shop.

As done previously for the oxy-fuel cutting process, it can also exemplify the time division of each plasma cutting process in a pie chart, as shown in Figure 7:

It is important to stress that the chart above is only an example, which has 12 pieces to cut, in a total of 69 m of cutting work. It is crucial to accent that the relative times can be significantly different, e.g., the marking time can sometimes be greater than the cutting time, depending on the pieces to be processed.

About the quality standards, the higher cutting quality of the plasma cutting process, compared with the oxy-fuel technology was evident by visual inspection. In the oxy-fuel cutting the presence of slag was very significant, when compared to the cuts done by the plasma system, where much smaller slag was formed, even in thicker steel plates. Visual inspection also testifies the much smaller kerf dimensions in the plasma cuts than the one of the oxy-fuel process.

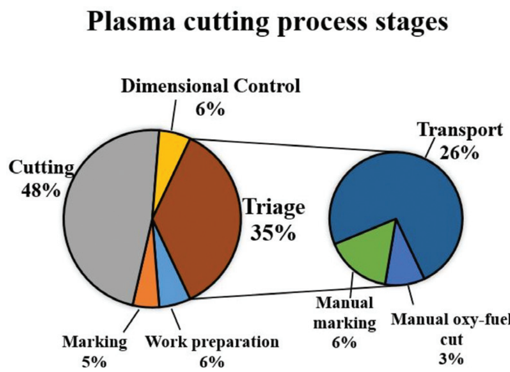

Figure 7. Time percentages of plasma cutting stages.

Although always some work must be done in order to eliminate the slag and prepare the surfaces to possible welds, this re-work will be much more extended in the steel plates cut by oxy-fuel than in the ones cut by plasma technology, due to the better cutting quality of the last one.

4 DISTRIBUTION OF CUTTING COSTS

The collected data also allow to obtain a better understanding of the cutting costs related to the steel cutting process in shipbuilding.

Leal & Gordo (2017) conducted a study related to the shipbuilding distribution costs structure. One of the activities studied was the steel cutting process. However, only the stages of effective cutting were analyzed, leaving out other stages of the cutting process.

Through the data collected and presented in this paper the cutting costs structure can be completed, as followed:

$$C_{\text{Cut Process}} = C_T + C_{ACprep} + C_{AM} + C_{AC} + C_{DC} + C_{MC} + C_{MM} \quad (4)$$

where

$C_{\text{Cut Process}}$ – Costs of the entire cutting process;
C_T – Costs of the electric transport inside the shop;
C_{ACprep} – Costs of the automatic cut preparation activity;
C_{AM} – Costs of the automatic marking activity;
C_{AC} – Costs of the automatic cutting activity;
C_{DC} – Costs of the dimensional control activity;
C_{MC} – Costs of the manual cutting activity;
C_{MM} – Costs of the manual marking activity.

Leal & Gordo (2017) deduced the elements of the formula C_T, C_{ACprep}, C_{AC}, and C_{MC}. Need to say that the cost estimation associated with the cut preparation is identical to the cost estimation of generic work preparation.

Assuming the costs of the manual marking are only labor associated costs and that the cost of the consumables can be neglected, then the C_{DC} and C_{MM} elements of the sum presented in formula 4 can be merged as follows:

$$C_{DC} + C_{MM} = n_m \,.\, S_m \,.\, (h_m + h_{dc}) \tag{5}$$

where

n_m – number of manual marking and dimensional control activities workers;
s_m – Marking workers wage [€/Mh];
h_m – marking time [h];
h_{dc} – dimensional control time [h].

The costs of the automatic marking activity, performed by the cutting machine, and monitored by the worker, can be given by the following formula:

$$C_{AM} = [(n_{tm} \,.\, S_{tm} \,.\, h_{am}) + (K_e \,.\, P_e \,.\, h_{am}) + (K_P \,.\, P_P \,.\, h_{am}) + (C_d \,.\, h_{am})] \tag{6}$$

where

n_{tm} – number of marking technicians;
S_{tm} – marking technicians wage [€/Mh];
h_{am} – automatic marking time [h];
K_e – electricity consumption [kW/h];
P_e – Electricity price [€/kW];
K_P – Propane consumption [kg/h or m3/h];
P_P – Propane price [€/kg or €/m3];
C_d – Cutting machine depreciation cost [€/h].

The linking of the present study and the study carried out by Leal & Gordo (2017), associating the cost estimation formulas present there with the time estimation formulas here developed, can be performed, allowing a faster and more direct understanding of the final costs of the cutting process, as function of the cutting technology.

5 CONCLUSIONS

The case study presented in this paper, although rather simple, takes a significant value proving the higher cutting speed of the plasma technology, when compared to oxy-fuel cutting. The studies already taken when comparing oxy-fuel and plasma cutting find their certification in this case study, relatively to the value of five times faster process of plasma cutting (GmbH 2005, Gordo *et al*. 2006).

Besides the cutting and marking activities itself, with obvious advantages for the plasma cutting, the difference of the preparation time required, that do not depend significantly on the amount of cut to be done, is rather interesting, proving the importance of the presence of actualized cutting system computer software.

Although the analysis done in this paper prove the higher cutting speed and quality of the plasma cutting, their implementation in the shipyard should be previously studied, analyzing its role in the block production flow.

As show in the fifth chapter, the formulas developed for the time estimation of each stage of the cutting process are key to allow a more trustful cost estimation of the cutting process.

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