ENVIRONMENTAL IMPACT OF PLATE FORMING BY LINE-HEATING METHOD

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ABSTRACT

In shipbuilding industry, there are various technological processes involved in building new ships having high potential for emission of pollutants into environment. An assessment of the impact level on environment due to building a certain ship requires an estimation of the individual impact of each technological process. The plate forming process is one of these technological processes which is carried out to accomplish the hull construction of a ship. In the plate forming process, the desired curved surface of a plate is formed from a flat one using mechanical and/or thermal methods, such as rolling, pressing and line-heating. The line-heating method is widely applied in forming complicated shapes of shell plating in shipyards. When the line-heating method is used in the forming process, a gas heat source is usually applied. Due to the combustion process of oxygen and the gaseous fuel, such as acetylene or propane, the heat energy required to form the plate is produced. Consequently, carbon dioxide, vapor, nitrogen, and other components are produced from the combustion. This research is devoted to study the impact of plate forming by the line-heating method on the emitted pollutants into environment, mainly the carbon dioxide. The influence of heating conditions on the bending angle is presented. The emitted CO_2 from the combustion process is estimated due to using acetylene or propane as a gaseous fuel. The relation between the bending angle and the changes of emitted CO_2 in plate forming is examined. In addition, the relationship between the emitted CO_2 and the degree of curvature in forming a bilge plate using the line-heating method is studied.

Keywords: Environment, Pollution, Emitted CO_2, Line-heating method, Plate forming

INTRODUCTION

The environmental concern has grown in the last few decades due to the increase of industrial pollutants emitted into the environment. To determine the impact level on the environment and natural resources from the different industrial processes, the emitted pollutants from each industrial processes should be evaluated. In shipbuilding industry, numerous technological processes such as cutting, forming and welding processes, are being carried out on steel plates and sections to construct a new ship or to repair an existing ship. The different technological processes involved in shipbuilding and ship repair industry will have a high potential for the emission of pollutants into environment. Hence, to make an evaluation for the impact level on environment in building a certain ship, the individual impact of each technological process should be estimated at first. The plate forming process is considered one of these technological processes which is necessary to form curved shell plating of most ships.

The shell plating of ship's hull may have a flat surface such as side shell, curved in one direction only such as bilge plates in the parallel middle body, or may have transverse and longitudinal curvatures such as those in the forward and aft parts of the hull. The desired curved surface of plate is formed from a flat one using mechanical and/or thermal methods, such as rolling, pressing and/or line-heating method. The relative importance of each method in plate forming depends mainly on the shape of the hull form. For example, in building 2400 TEUs container ship, which has a fine form, in one of the Spanish shipyards, the line-heating method is used to form 90% of the plates to be formed and the rest by the mechanical methods [1]. On the other hand, in building product tanker of 46000 DWT in the same shipyard, 35% of the plates were formed by the line-heating method and 65% by the mechanical methods. These two figures indicate the relative importance of the line-heating method in forming steel plates with other methods in shipyards.

The line-heating method has been applied in forming shell plating of ships since 1950 in Japan. Hashimoto [2] made a report about this method and its applicability in plate forming in Ishikawajima-Harima Heavy Industries (IHI) as a practical plate forming method. Afterwards, different researchers attempts to recover the skills of craftsmen and automate the plate forming process using the line-heating method [2-11]. The line-heating method can be defined simply as the process of forming steel plates by controlled heating and cooling. If a plate is heated using a certain heating source, thermal stress is induced in the heated region producing strain in the whole domain of the plate. Due to the temperature rise in the heated portion, the magnitudes of Young's modulus and yield stress of the material decrease. The adjacent material to the heated region, due to its lower temperature than the heated one, will resist the thermally created stress. Thus, the heated region will be constrained by the surrounding material and after releasing the heat source and cooling some permanent plastic, deformation is retained in the plate. In the heated region, compressive plastic deformation is produced and subsequently the material of the plate shrinks. The surface imposed to the heat source contracts more than the other side resulting in bending angle as shown in Figure 1. This behavior of plate due to the heating process is utilized in forming curved steel plates as well as in removing distortion from parts, sub-blocks and blocks.

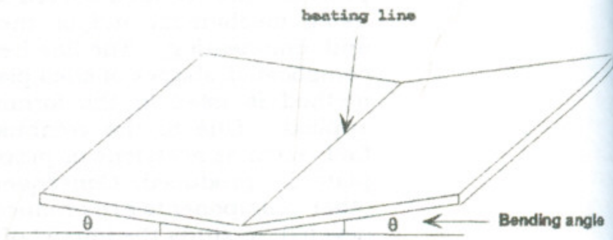

Figure 1 Bending of plate around the heating line.

When the line-heating method is used in plate forming, a gas torch, such as oxy-acetylene or oxy-propane, is usually applied as a heating source. As a result of the combustion process, carbon dioxide, vapor, nitrogen and other components are produced. Therefore, certain impact on environment will take place due to the emitted unfavorable gases. The line-heating method is considered a vital tool in forming complex shapes of steel plates. Thus, this research is devoted to study the environmental impact of plate forming using the line-heating method, mainly the emission of CO_2. The relationship between the heating conditions and the bending angle of steel plates is explained. The emitted CO_2 from the combustion process due to applying acetylene or propane is estimated.

The relation between the bending angle and the changes of emitted CO_2 in plate forming is examined. The emitted CO_2 in forming bilge plate using the line-heating method is determined to evaluate the influence of the degree of curvature on the emitted pollutant .

HEATING CONDITIONS AND BENDING ANGLE

In forming shell plating by the line-heating method, plastic deformation is created in the heated zone which bends the plate mainly in the perpendicular direction to the heating line. As a matter of fact, the magnitude of bending angle that occurs depends on the maximum surface temperature and its distribution in the domain of the plate [9]. When a gas heating source is used, the maximum temperature of the heated plate surface depends on the effective heat input rate, Q, the torch speed V and the plate thickness h. The effective heat input rate, Q, can be represented through the acetylene and oxygen flow rates, their pressures and the height of the torch from the surface of plate to get the maximum surface temperature. On the other hand, the temperature distribution through the thickness of the plate is influenced by the previous parameters and the cooling method. In addition, the thermal properties of the plate material will have certain effect on the temperature field, while the mechanical properties will affect the resulting bending angle.

The main heating conditions which control the plate bending by the line-heating method are the pressure, the flow rate of both the fuel gas and oxygen and the torch speed. Subsequently, after defining the heating conditions, the magnitude of bending angle produced by the heating line will be function of the plate thickness and the cooling conditions. Different experimental studies were carried out to study the plate bending by the line-heating method [1, 11]. Tsuji and Okumura [11] used oxy-acetylene torch as a heat source in their experimental work to study steel plate forming by the line-heating method. On the other hand, Antonio and Carlos [1] carried out their experiment using oxy-propane as a heating source to train craftsmen how to use the line-heating method for accurate bending of plates.

A series of experimental work on steel plate models were made by Tsuji and Okumura using oxy-acetylene flame. The length and the breadth of the models were fixed, 1.0×0.5 m, while three different thicknesses, 12, 16 and 19 mm, were used in the experiments. The average yield stress of the material of the plate is 240 MN/m^2. In addition, three different values of acetylene flow rates, 0.960, 1.920, and 2.880 m^3/hr were selected in their analysis and the corresponding oxygen flow rates were 1.14, 2.10 and 3.06 m^3/hr, respectively. Also, the tip height of the torch from the plate surface were 20 mm for the acetylene flow rate 1.14 m^3/hr, and 26 mm for the other acetylene flow rates to get the maximum surface temperature. The torch speed ranges from 0.0025 to 0.010 m/s and travels in the longitudinal direction. The acetylene pressure was 49 kN/m^2 while the oxygen pressure was 490 kN/m^2. The produced bending angles corresponding to the torch speed, acetylene flow rate, and the maximum surface temperature are given in Table 1 for plate thickness 12 mm. Similar data and results for plate thicknesses 16 and 19 mm together are given in Table 2. It is clear from Tables 1 and 2 that as the torch speed decreases, for certain acetylene flow rate and plate thickness, the maximum surface temperature increases and subsequently the bending angle increases. In addition, one can note that the maximum surface temperature increases as the torch speed decreases. Generally, the maximum surface temperature should not exceed 650 $^{\circ}C$ to prevent material deterioration. Also, one can notice that increasing acetylene flow rate for certain torch speed and plate thickness does not change greatly the magnitude of produced bending angle.

Antinio and Carlos [1] carried out their experimental work on ordinary-strength Grade A steel, the yield stress is about 240 MN/m^2, using propane as fuel gas. They used large flame with a torch tip-to-plate distance between 20 mm and 28 mm to get the maximum surface temperature. The propane and oxygen pressures were 81 kN/m^2 and 588 kN/m^2, respectively. Also, the selected propane flow rates were 1.5, 2.2, 2.6 and 3.2 m^3/hr and the corresponding oxygen flow rates were 7, 10, 13 and 16 m^3/hr, respectively. Water cooling was applied on the same side of heated surface and the water jet-to-flame distance is about 100 mm. With these working conditions, the maximum surface temperature was under 650 °C. The bending angles for different plate thicknesses are shown in Table 3. It is clear from Table 3 that the bending angle generally increases for thinner plates at constant torch speed.

Table 1 Heating conditions and bending angle for plate thickness h = 12 mm [11].

Acetylene flow rate m^3/hr	Torch speed V m/s	Maximum surface temperature °C	Bending angle $\theta \times 10^3$ radian
0.960	0.0075	578	6.6
0.960	0.0050	695	12.5
0.960	0.0025	928	39.5
1.920	0.0100	634	8.7
1.920	0.0075	715	14.8
1.920	0.0050	820	36.0
2.880	0.0100	738	15.9
2.880	0.0075	825	30.1
2.880	0.0050	960	57.0

Table 2 Heating conditions and bending angle for plate thicknesses equal to 16 mm and 19 mm [11].

Acetylene flow rate m^3/hr	Torch speed V m/s	Plate thickness = 16 mm		Plate thickness = 19 mm	
		Max. surface temp. °C	Bending angle $\theta \times 10^3$ radian	Max. surface temp. °C	Bending angle $\theta \times 10^3$ radian
0.960	0.0075	577	5.1	558	4.2
0.960	0.0050	685	7.9	698	6.7
0.960	0.0025	877	15.8	889	12.4
1.920	0.0075	716	6.8	810	5.9
1.920	0.0050	854	9.7	935	8.5
1.920	0.0025	1051	15.8	1171	15.9
2.880	0.0075	827	9.3	890	8.0
2.880	0.0050	979	14.4	1040	11.3
2.880	0.0025	1176	24.4	1270	16.5

Table 3 Heating conditions and bending angle due to using propane [1].

Plate thickness h (mm)	Propane flow rate m^3/hr	Torch speed V m/s	Maximum surface temperature °C	Bending angle $\theta \times 10^3$ radian
12	1.500	0.0067	500	9.4
14	1.500	0.0050	550	8.6
15	2.200	0.0050	500	7.2
16	2.200	0.0050	500	7.2
18	2.200	0.0050	500	7.2
19	2.600	0.0050	500	8.6
20	2.600	0.0042	600	7.9
22	2.600	0.0033	600	7.2
25	3.200	0.0033	600	9.4
28	3.200	0.0042	500	7.2
30	3.200	0.0042	500	6.5
40	3.200	0.0042	500	4.3

EMITTED CO_2 IN THE HEATING PROCESS

When the line-heating method is used in forming shell plating of ship structure, the pollutant component CO_2 is emitted as one component of combustion. Different hydrocarbon gases, such as acetylene and propane, can be used for the heating process. The CO_2 is created from the combustion process between oxygen and hydrocarbon gases. Thus, if the mass flow rate of the fuel gas is calculated based on its working conditions such as pressure, flow rate and temperature, then the mass flow rate of emitted CO_2 can be estimated assuming complete combustion of the hydrocarbon gas. The mass flow rate of CO_2, of course, will depend on the type of fuel gas and its flow rate.

Emitted CO_2 from Using Acetylene

The mass flow rate of CO_2 emitted from the combustion process can be estimated based on the mass flow rate of acetylene assuming complete combustion. Owing to the low pressure of acetylene, the acetylene can be considered as an ideal gas. Thus, the mass flow rate of acetylene, $m_{acet.}$, can be calculated based on the state equation of ideal gases [12-14], such that

$$m_{acet.} = PV/RT \quad \text{kg/hr} \qquad (1)$$

where P = pressure of acetylene, N/m^2.
V = acetylene flow rate, m^3/hr
T = absolute temperature of acetylene, deg. K
R = acetylene gas constant = 320 J/kg.K

If the pressure, the flow rate and the temperature of acetylene are known, the mass flow rate of acetylene, $m_{acet.}$, can then be calculated based on Equation 1.

The acetylene is a hydrocarbon of the C_nH_{2n-2} unsaturated group and it has the chemical formula C_2H_2 [12], therefore the reaction equation for complete combustion can be considered as follows [13-14]:

$$C_2H_2 + 2.5O_2 \rightarrow 2CO_2 + H_2O \qquad (2)$$

1 mol	2.5 mol	2 mol	1 mol	volume basis
26 kg	80 kg	88 kg	18 kg	mass basis

This means that, for complete combustion one volume-unit of acetylene requires two-and-half volume-units of oxygen. Although Equation 2 does not give a complete picture of the combustion, as the fuel undergoes some intermediate transformations, the mass flow rate of emitted CO_2, $m_{carbdiox.}$, may be estimated from equation (2). Based on the mass balance given in equation (2), the mass flow rate of emitted CO_2, $m_{carbdiox.}$, is computed such that:

$$m_{carbdiox.} = (88/26) \times m_{acet.} \qquad (3)$$

Assuming the pressure of acetylene, P, is equal to 1 N/m^2, its flow rate, V, is 1.0 m^3/hr, and temperature, T, is 273 K, the mass flow rate of acetylene, $m_{acet.}$, will be 1.145×10^{-5} kg/hr. Thus, the mass flow rate of emitted CO_2, $m_{carbdiox.}$, will be 3.88×10^{-5} kg/hr. The pressure of acetylene applied in Tsuji's experiment was 49 kN/m^2 and the emitted CO_2 corresponding to the different acetylene flow rates is given in Table 4. It is clear from this table that the emitted CO_2 increases as the acetylene flow rate increases.

Table 4 Mass of emitted CO_2 due to acetylene.

Acetylene flow rate (m^3/hr)	Mass of emitted CO_2 (kg/hr)
0.960	1.8160
1.920	3.6328
2.880	5.4492

Emitted CO_2 from Using Propane

In a similar manner, owing to the low pressure of propane, ideal gas equation can be used to present the state of propane. Thus, the mass flow rate of propane, $m_{prop.}$, can be calculated based on the law of ideal gas, such that

$$m_{prop.} = PV/RT \quad \text{kg/hr} \qquad (4)$$

where P = pressure of propane, N/m^2.
V = propane flow rate, m^3/hr.

T = absolute temperature of propane, deg. K.

R = propane gas constant = 189 J/kg.K.

The mass flow rate of propane, $m_{prop.}$, will be calculated from Equation 4.

The equation representing the complete combustion of propane with oxygen should be written at first to estimate the mass flow rate of emitted CO_2. The propane is a hydrocarbon of C_nH_{2n+2} group and it has the chemical formula C_3H_8 [13]. Therefore the reaction equation for complete combustion can be described by the following equation [13-14]:

$$C_3H_8 + 5O_2 \Rightarrow 3CO_2 + 4H_2O \qquad (5)$$

The mass flow rate of emitted CO_2, $m_{carbdiox.}$, induced from complete combustion can be estimated as follows,

$$m_{carbdiox.} = 3.0\ m_{prop.} \qquad (6)$$

If the pressure of propane, P, is assumed to be 1.0 N/m^2, the flow rate V is 1.0 m^3/hr, and the temperature T is 273 K, the mass flow rate of propane will be 1.94×10^{-5} kg/hr. The emitted CO_2 will be 5.8×10^{-5} kg/hr. In Antonio's experiments, the pressure of propane was 81 kN/m^2, and the emitted CO_2 corresponding to the propane flow rate is given in Table 5. The same conclusion about the increase of emitted CO_2 due to the increase in propane flow rate is also valid.

Table 5 Mass of emitted CO_2 due to propane.

Propane flow rate (m^3/hr)	Mass of emitted CO_2 (kg/hr)
1.500	7.064
2.200	10.364
2.600	12.248
2.800	13.190
3.200	15.074

BENDING ANGLE AND EMITTED CO_2

From the previous section it is noted that the magnitude of emitted CO_2 in the heating process is a function of the fuel gas flow rate and the time consumed in the heating process. Subsequently, the relationship between the emitted CO_2 in the plate forming process by the line-heating method can be explained based on the fuel gas flow rate. However, the bending angle in the line-heating method depends mainly on the maximum surface temperature which is influenced by the effective heat input rate, the torch speed and the thickness of the plate. The type of the used fuel gas affects greatly the effective heat input rate to the plate. Thus, to examine the changes of emitted CO_2 in the plate forming by the line-heating method, the effect of heating conditions together with the plate thickness on the emitted CO_2 in the heating process will be discussed firstly. The effect of used fuel gas type on the emitted CO_2 is then examined for the unit bending angle.

Effect of Heating Conditions

The experimental results carried out by Tsuji and Okumura [11] are considered good data to analyze the influence of heating conditions on the changes of emitted CO_2 in the heating process. To reflect the influence of the torch speed in the plate forming process, the mass of emitted CO_2 is estimated in kilogram per unit length of the heating line. The mass of emitted CO_2 per unit length is plotted against the bending angle θ, as shown in Figure 2, for each plate thickness and acetylene flow rate. It is clear from Figure 2 that for a constant bending angle, the emitted CO_2 increases as the acetylene flow rate increases for constant plate thickness. Thus, for a certain thickness of plate, the emitted CO_2 can be reduced by decreasing the acetylene flow rate. However, to reduce the acetylene flow rate, the torch speed should be decreased also and the bending angle will decrease after a certain speed [9]. On the other hand, at a constant bending angle, as the thickness of the plate increases, the emitted CO_2 increases rapidly for a constant acetylene flow rate. This increase in the emitted CO_2, for constant acetylene flow rate, is due to the fact that the heat energy required to form the plate increases as thickness increases. In addition, for a constant acetylene flow rate and thickness of plate, the emitted CO_2 increases as the bending angle increases. However, the maximum permissible surface temperature is limited to 650 °C, so that the maximum bending angle is constrained to that temperature.

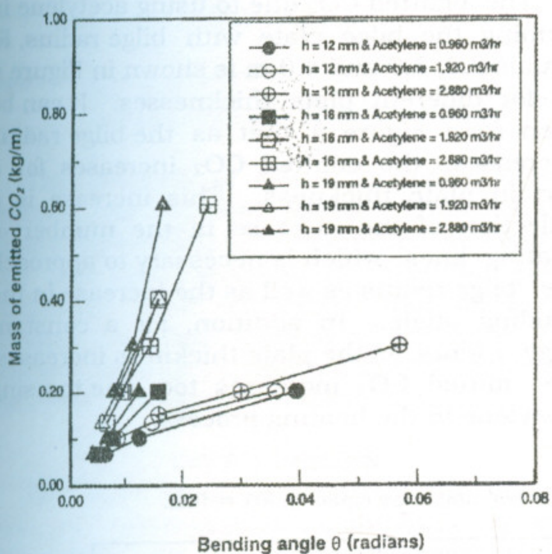

Figure 2 Relation between estimated mass of emitted CO_2 and bending angle θ

Effect of Fuel Gas Type

In the line-heating method, the heat energy applied in the forming process can be produced from different fuel gases, for example, acetylene , propane, etc.. The most common gas fuels used in forming steel plates by the line-heating method are acetylene and propane. To examine the effect of using propane or acetylene on the emitted CO_2, the magnitude of emitted CO_2 should be evaluated for the same bending angle and plate thickness. Hence the emitted CO_2 is computed for the same bending angle, equal to 0.001 radian, produced when using acetylene or propane for the same plate thickness as given in Table 6. It is clear from Table 6 that to produce bending angle equal 0.001 radian, the mass of emitted CO_2 from applying propane gas fuel becomes 3 times that emitted from using acetylene. However, this ratio is slightly greater than expected due to using wide propane flame. Thus, when applying acetylene in the heating process, the magnitude of the mass of emitted CO_2 will decrease.

EMITTED CO_2 IN FORMING A BILGE PLATE

To clarify the relationship between the emitted CO_2 and the forming degree of plate by the line-heating method, forming a bilge plate of radius R is considered. It is assumed that the length of the flat plate is L, its width is W, and the thickness of the plate is t. The number of heating lines is estimated using the proposed method in reference [15]. In this method, the plate is assumed to be divided into a number of lengthwise strips to achieve the desired curve in the width direction. The number of heating lines, NOHL, is estimated based on the width of strip, Δw, that approximates the actual shape, as shown in Figure 3, such that:

$$NOHL = W/\Delta w - 1 \tag{7}$$

The width of each strip, Δw, is determined based on the permissible deviation, δ, between the approximate shape, which can be created by the line-heating method, and the desired shape and the radius of curvature, R, such that:

$$\Delta w = 2R \sin(\theta) \tag{8}$$

where, $\theta = \cos^{-1}(1 - \delta/R)$

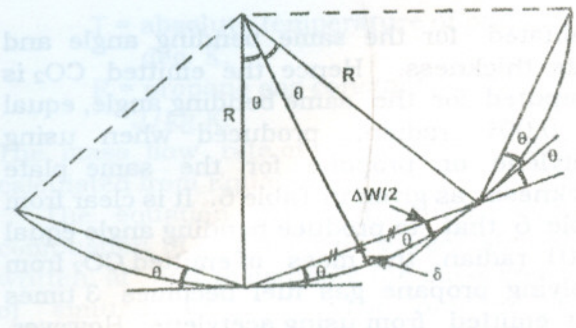

Figure 3 Approximate division of the flate plate into strips to estimate the number of heating lines.

Thus, by knowing the desired radius of curvature R with the permissible error, δ, the permissible bending angle, θ, and the width of the strip can be determined from Equation 8. The number of heating lines necessary to get the bilge plate can be estimated from Equation 7. Based on the permissible bending angle, θ, or the bending angle that can be created by the line-heating method, the width of strips can be computed.

Afterwards, the number of heating lines can be predicted from Equation 7, and with the length of the plate, the mass of emitted CO_2 can be estimated.

To present the relation between the degree of forming and the emitted CO_2, suppose that the length and the width of the bilge plate, L and W are equal 6.0 and 1.0 m, respectively. Also, suppose that the bilge radius, R, ranges from 2.0 m to 4.0 m. The number of heating lines necessary to approach the bilge radius will vary with the radius of curvature and the permissible error δ. The number of heating lines, based on the previous data, is estimated for δ equal 1.0 mm as shown in Table 7. It is clear from Table 7 that as the radius of curvature decreases, the required number of heating lines increases, for example, 7 heating lines for R equals 2.0 m. On the contrary, as the radius of curvature increases, the number of heating lines decreases for the same width of the plate, 5 heating lines for R equals 4.0 m.

The emitted CO_2 due to using acetylene in forming the bilge plate with bilge radius, R, equals 2.0, 3.0 and 4.0 m is shown in Figure 4 for different plate thicknesses. It can be seen from Figure 4 that as the bilge radius decreases, the emitted CO_2 increases for a certain plate thickness. This increase is a reflection of the increase in the number of heating lines which is necessary to approach the bilge radius as well as the increase in the bending angle. In addition, for a constant bilge radius, as the plate thickness increases, the emitted CO_2 increases too due to using acetylene in the heating process.

Table 6 Mass of emitted CO_2 due to propane and acetylene for bending angle equal 0.001 radian.

Plate thickness h (mm)	*m_{prop} for 0.001 radian of bending angle (kg/m)	*$m_{acet.}$ for 0.001 radian of bending angle (kg/m)	m_{prop} / m_{acet}
12	0.031	0.010	3.00
16	0.080	0.026	3.00
19	0.079	0.048	1.64

*m_{acet} = mass of emitted CO_2 due to acetylene (kg/m).
*m_{prop} = mass of emitted CO_2 due to propane (kg/m).

Table 7 Estimated number of heating lines in forming bilge plate.

Bilge Radius R (m)	Required bending angle θ (radian)	Number of heating lines (NOHL)
2.0	0.0316	7
3.0	0.0258	6
4.0	0.0224	5

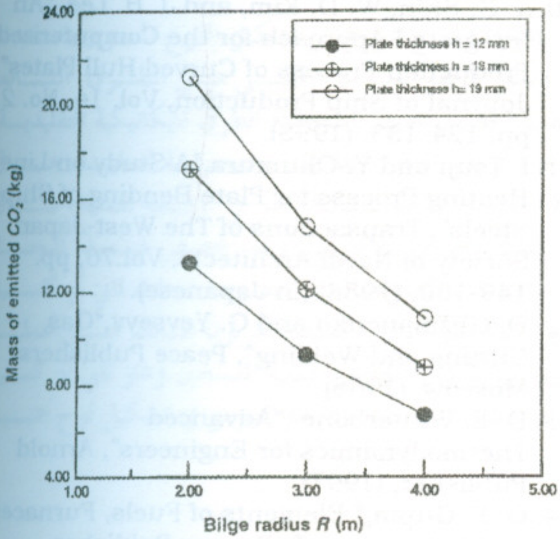

Figure 4 Relationship between estimated mass of emitted CO_2 and bilge radius R in forming bilge plate using line-heating method.

This increase is due to the higher energy required for thicker plates. Thus, as the number of heating lines is known, the emitted CO_2 can be estimated for a certain plate thickness. One can expect that when the propane is used instead of acetylene, the previous quantity of emitted CO_2 will increase than that produced from acetylene.

CONCLUSIONS

To make an assessment of the impact level on environment in shipbuilding and ship repair industry, the pollutants emitted from various technological processes should be evaluated. In the plate forming using the line-heating method, the pollutant gas CO_2 is emitted from the combustion process. In this paper, the environmental impact of plate forming using the line-heating method, mainly the emission of CO_2, is studied. From this study the following conclusions can be drawn:

1. The emitted CO_2 decreases as the fuel gas flow rate decreases and this will be accompanied by slowness of torch speed up to a certain level to get the required bending angle. This in turn will increase the forming time.
2. When the plate thickness becomes thicker, both the necessary forming energy and the emitted CO_2 increase.
3. The emitted CO_2 due to applying propane in the heating process is greater than that emitted due to using acetylene for the same plate and bending angle.

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التأثير البيئي لتشكيل الألواح باستخدام طريقة خط التسخين

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قسم الهندسة البحرية وعمارة السفن- جامعة الاسكندرية

ملخص البحث

في صناعة بناء السفن, تعتبر العمليات التكنولوجية المختلفة المستخدمة في بناء سفن جديدة ذات قدرات عالية لانبعاث المواد الضارة للبيئة. لعمل تقييم لمستوى التأثير الضار بالبيئة نتيجة لبناء أو إصلاح سفينة, يستلزم تحديد أولا تأثير كل عملية تكنولوجية مستخدمة في البناء أو الإصلاح كل على حده. وتعتبر عملية تشكيل الألواح إحدى هذه العمليات التكنولوجية التي تستخدم لاتمام

بناء جسم السفينة. في عملية تشكيل الألواح , يتم الحصول على الشكل المطلوب للوح عن طريق تشكيل اللوح المستوى باستخدام الطرق الميكانيكية/الحرارية مثل الدلفنة, الكبس وطريقة التسخين الخطى. وتعتبر طريقة التسخين الخطى من الطرق الشائعة الاستخدام في عملية تشكيل الألواح ذات أسطح لها انحناءات مركبة ويصعب الحصول عليها باستخدام الطرق الميكانيكية التقليدية. وعند استخدام طريقة التسخين الخطى في التشكيل, يستخدم عادة مصدر حراري من الوقود الغازي. ونتيجة لعملية احتراق الأوكسجين والوقود الغازي, مثل الأسيتيلين أو البر وبين, يتم إنتاج الطاقة الحرارية اللازمة لتشكيل اللوح. ونتيجة لعملية احتراق الغازات, يتم انبعاث كل من ثاني أو كسيد الكربون, النتروجين, بخار الماء وبعض العناصر الأخرى. ولهذا خصص هذا البحث لدراسة تأثير عملية تشكيل الألواح باستخدام طريقة التسخين الخطى على الانبعاثات الضارة بالبيئة, خصوصا انبعاث ثاني أو كسيد الكربون. لذلك تم عرض تأثير حالات التسخين على زاوية الثني. تم تقدير كمية غاز ثاني أو كسيد الكربون المنبعث من عملية احتراق كل من غاز الأسيتيلين و البر وبين. بعد ذلك تم اختبار العلاقة بين زاوية الثني الناتجة من عملية التسخين وغاز ثاني أو كسيد الكربون المنبعث. بالإضافة إلى ذلك, تم دراسة العلاقة بين غاز ثاني أو كسيد الكربون المنبعث ودرجة التقوس في تشكيل لوح جمة السفينة باستخدام طريقة التسخين الخطى.