POLISH MARITIME RESEARCH Special Issue 2018 S1 (97) 2018 Vol. 25; pp. 134-144
10.2478/pomr-2018-0034

ASSESSMENT OF TECHNOLOGICAL USEFULNESS OF PANEL PRODUCTION LINE IN SHIPBUILDING PROCESS

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ABSTRACT

This paper presents assessment of technological usefulness of panel production line in prefabrication process of large ship hull sections, in which special attention is paid to producibility of welding operations. Basing on the assessment these authors worked out hierarchy of analyzed sequences of welding technological processes as well as production line stands used for the processes. The assessment was performed on the basis of analysis of a concept of panel production line based on real production lines functioning in shipbuilding industry, as well as technical documentation of typical hull sections of a multi-purpose ferry. The presented analysis took into account impact of technological - constructional parameters onto producibility of welding process of prefabricated sections. Among these parameters the following were numbered: mass of the sections and number of their elements, total length of welds, labour consumption, material consumption as well as linear heat input in welding operations. On the basis of the achieved results, places which worsen effectiveness of production line operation were identified, as a result it was possible to formulate proposals for modernization of flow prefabrication line for hull sections.

Keywords: panel production line, welding technology, SAW, SAW-tandem, GMAW-tandem, FCAW, ship hull

INTRODUCTION

Contemporary hulls of sea-going ships are large spatial bodies assembled with several dozen and often more than a hundred (sometimes even several thousand) structural sections of different types. Despite of geometrical diversity between particular structural modules resulting mainly from a given type of ship and region of structure, the main component of every large-size ship hull section is a flat stiffened panel. Therefore prefabrication of stiffened panels conducted usually on a special production line being a part of flow production system constitutes very important element of production process in every shipyard.

The production line used for prefabrication of thin-walled flat sections (PPL - panel production line) is a compact technological line composed of assembly stands and welding stands.

The panel production line makes it possible to produce complete stiffened panels which are the basis for structural modular sections as well as blocks to be used in subsequent stages of ship hull prefabrication process.

Worth remembering that joining the prefabricated technological subassemblies (during flow production of stiffened panels) as well as sections and blocks can be performed efficiently only in the case of obeying an appropriate assembly plan [1], [2].

Ships in production of which the panel production lines suit ideally are those of hulls with many flat surfaces, for instance: ferries (passenger and passenger-car ones), Ro-Ro ships, Con-Ro multi-purpose ships (Fig. 1 shows an exemplary assembly plan of such ship). Hulls of the above mentioned very special types of ships are produced with regime of narrowed tolerances, on account of, a. o., large number of additional outfitting elements. Hence for their building, technological usefulness of panel production line becomes especially important as it directly impacts subsequent technological processes.

Technological usefulness of the production line is directly associated with the notion of producibility of welded structures, which, through rational selection of factors influencing production process, has to provide structure with required quality at possibly lowest expense of production resources and time [3], [4]. This is especially important for prefabrication of a large number of flat sections which, in case of the ship shown in Fig. 1, amounts to several hundred.

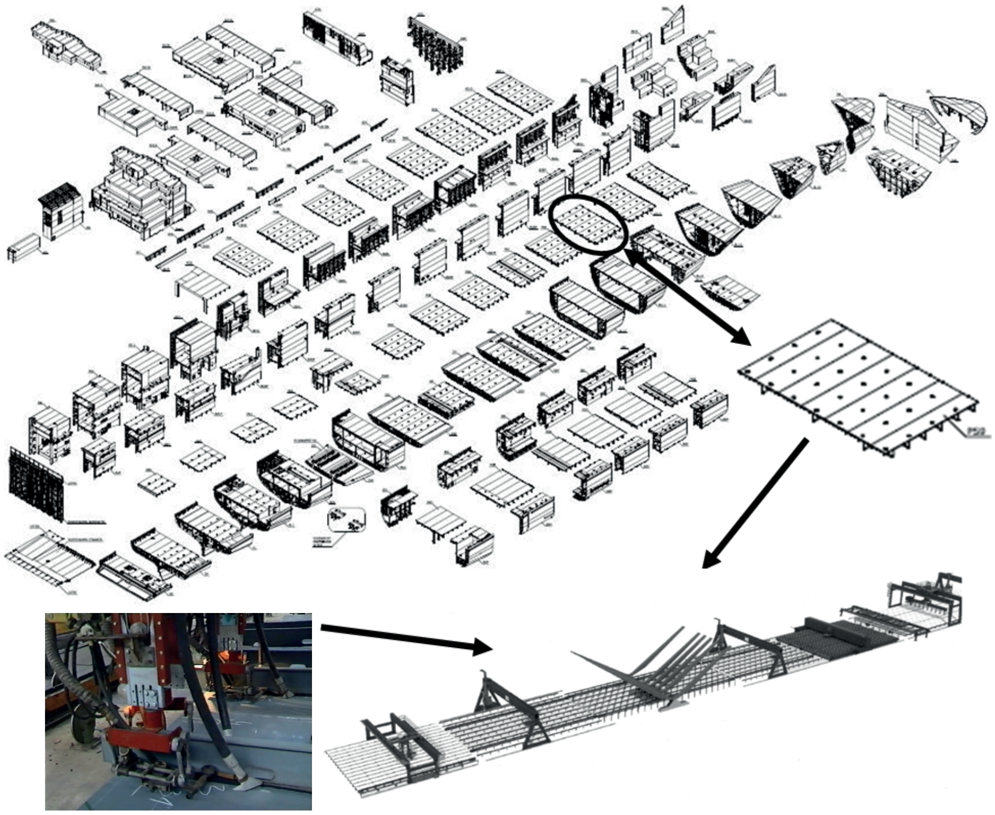

Fig. 1. Expanded isometric drawing of hull structure of a Con-Ro multi-purpose ship and a model of flow production line of flat sections (panels)

Therefore, welding operations are crucial from the point of view of PPL effectiveness as they decide on capacity of the whole prefabrication line. For this reason the presented paper is focused on analyzing four sequences of systems of welding technological processes as well as, consequently, on identifying neuralgic areas of the PPL (i.e. those impairing its capacity). Worth remembering that the assessment of all aspects associated with PPL functioning is a complex and difficult issue as it requires to look at the issue form many points of view, not only from that of welding processes (but also assembling and correcting processes – mainly straightening operations, as well as economic aspects associated with all the above mentioned processes) in order to increase objectivity of such assessment as much as possible. Hence an attempt to do such a complex look requires separate analyses. As it seems to be rather wide issue this paper has been limited to presentation of an analysis dealing with welding technologies only.

For the analysis a flow production line based on the concept of real panel production lines today functioning in shipbuilding industry on which typical ship-hull two-stiffener sections can be prefabricated, was selected.

The below described configuration of the panel production line as well as welding technologies used on it were selected on the basis of available subject-matter literature dealing with production of welded joints, e.g. [5] ÷ [10] (including issue of mechanized welding stands), analysis of welding technology procedures, e.g. [11], [12], supported by expert knowledge and industrial experience.

The proposed configuration consists of seven main stands (see Fig. 2a), namely:
1 – stand for assembling plate sheets,
2 – stand for welding butt joints in plates,
3 - stands for assembling 1st order stiffeners fitted with the use of turntable,
4 – stand for welding 1st order stiffeners,
5 – stand for assembling 2nd order stiffeners,
6 - stand for welding 2nd order stiffeners,
7 – stands for finishing (i.e. assembling and welding of remaining elements of panel) as well as appropriate acceptance procedures.

The used nomenclature dealing with degree of the order of panel stiffeners results from technological procedure where assembling sequence of stiffeners during prefabrication of panels decides on a rank of stiffener order. Hence, flat bars,usually bulb-flats, are considered 1st order stiffeners, and web plates and frame flanges – 2nd order stiffeners.

Worth remembering that number of stands of panel production line may be either lowered or increased depending on scale of production, types of sections as well as degree of process mechanization, e.g. by adding two additional stands, namely:

- A panel turn-over stand – applied in case when one-side welding technology is not sufficient for the designed shell plates. The stand should be fitted with e.g. turn-over scaffolding for plate sections (called also panel turntable) or a gantry crane fitted with special equipment;
- A stand for panel preparation to assembling stiffeners. Such stand should be equipped with a multi-purpose automatic gantry for: shot- peening, lofting as well as panel's outline cutting.

The following technologies for producing welded joints were selected:

- SAW or SAW -tandem system – for plate butt welding (SAW - Submerged arc welding with wire electrode, [14]),
- SAW or GMAW (both in tandem system) – for welding 1st order stiffeners (GMAW - Gas-shielded Metal Arc Welding, [14]). In the analyzed case MAG technology (MAG - Metal-arc active gas welding, [14]) was used.
- FCAW – for welding 2nd order stiffeners as well as stiffening-up elements (FCAW - Flux-cored wire metal-arc welding with active gas shield, [14]),

which constitute components of sequences of analyzed welding technology systems used in panel production line (see Fig. 2b), as presented in Tab. 1.

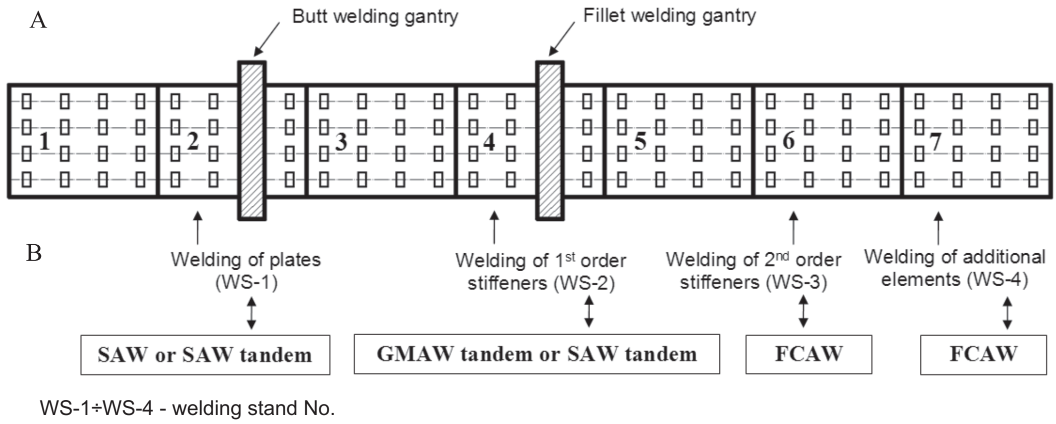

Fig. 2. Main stands - components of panel production line (A) acc. [13] with marked welding stands and technologies (B) subjected to analysis.

Tab. 1. Sequences of analyzed welding technology systems used in panel production line

Sequence No.	Welding stand No. (see Fig. 2B)				
	WS-1	WS-2	WS-3	WS-4	
1	SAW	GMAW tandem	FCAW	FCAW	**Welding technology**
2	SAW	SAW tandem	FCAW	FCAW	
3	SAW tandem	GMAW tandem	FCAW	FCAW	
4	SAW tandem	SAW tandem	FCAW	FCAW	

ANALYSIS OF WELDING TECHNOLOGIES USED IN PANEL PRODUCTION LINE

The analysis is aimed at presentation of possible utilization of technological – constructional parameters of flat sections as well as parameters of welding processes for assessing the technological usefulness of panel production line and hence possible interference into flow production system of stiffened panels.

The analysis was worked out on the basis of simulations carried-out with making use of the assumed sequences of welding technology systems (see Tab. 1), and the above mentioned crucial parameters among which the following were numbered:

- technological-constructional parameters of sections: their masses, number of elements, number and length of welds, as illustrated in Fig. 3,
- technological parameters of welding processes: welding parameters together with technical details of preparation of welds, as exemplified for selected welding technologies in Fig. 4 and Tab. 2.

The above specified parameters of welding processes are in compliance with the requirements of rules of ship classification institutions technological procedures approved by the institutions and being in force in the shipyard, i.e., for instance: [11], [12], as well as technological standards concerning the use of additional materials (being in line with a. o. [15]).

20 typical two-row stiffened panels (having also additional elements such as stiffening-up brackets, flat bars etc) of the multi-purpose ferry were selected for the analysis. The sections were so selected as to get their geometrical variety as large as possible, e.g.: the minimum dimensions (i.e. length x breadth) of welded sheets amounted to 4500x5000 mm, and maximum ones to 12600x11900mm. The analyzed sections (see Fig.3 A) were hierarchically ordered, regarding their masses, beginning from the smallest up to the greatest value. The hierarchy is kept in all subsequent drawings of this paper (i.e. Section No.1 is that of the smallest mass, whereas Section No. 20 – of the greatest mass). Basic quantitative absolute and percentage relations for the analyzed sections are given in Fig. 3. They were worked out on the basis of technical documentation of typical sections of a multi-purpose ferry, which were made available by one of Polish shipyards. Length of welds shown in Fig. 3E and 3F is the total length from the technological point of view, i.e. that which takes into account number of welding seams.

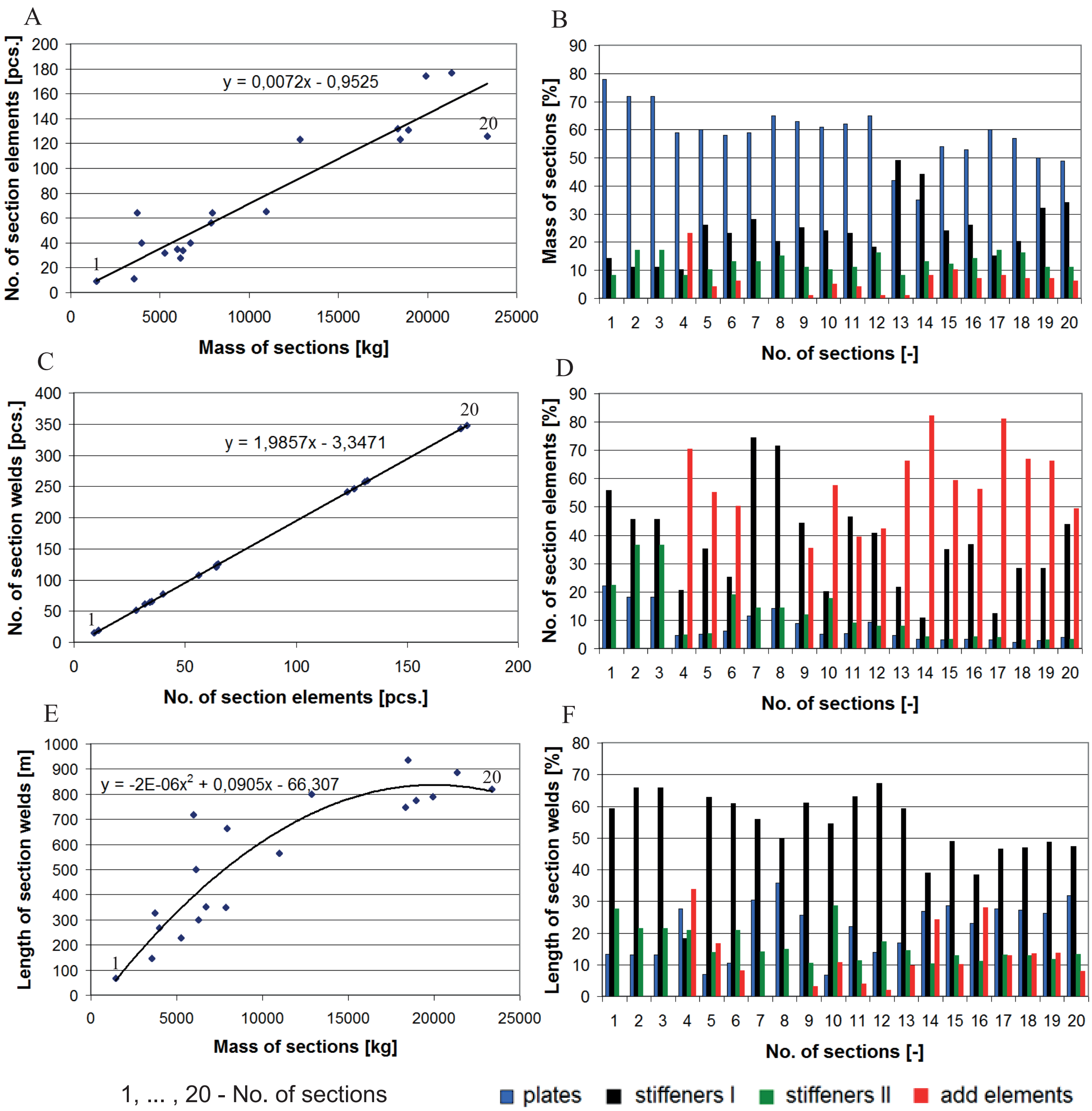

Fig. 3. Basic quantitative absolute and percentage relations for the analyzed sections:
A – mass of sections versus number of their elements,
B – mass of particular groups of welded elements related to mass of sections,
C – number of section elements versus number of welds,
D – number of particular groups of welded elements related to number of section elements,
E – mass of section versus length of welds,
F – length of welds in particular groups of elements related to total length of section welds

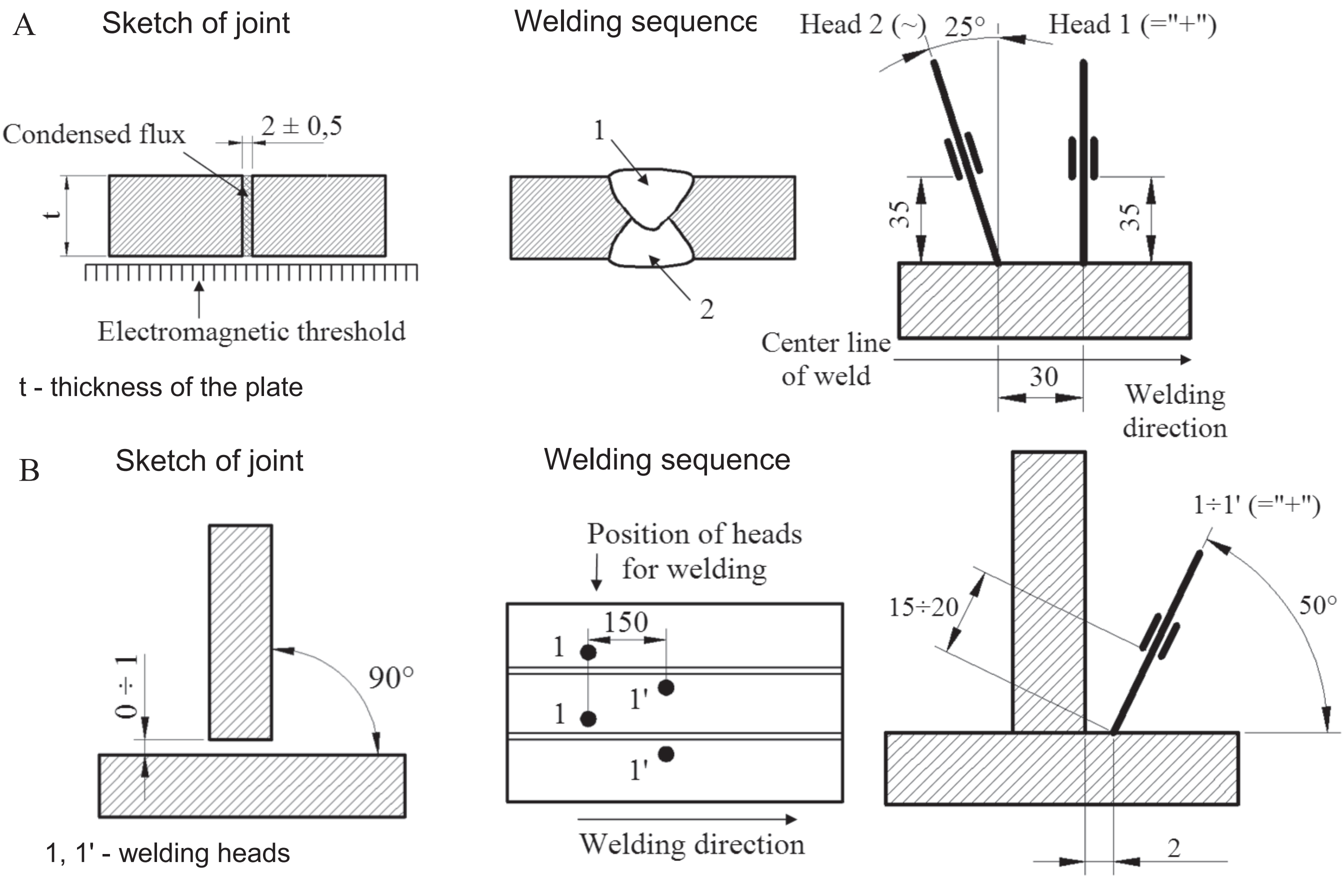

Fig. 4. Details of preparation of elements to welding with the use of SAW-tandem technology:
A – butt joint with butt weld,
B – T–joint with fillet weld (acc. [12])

Tab. 2. Examples of technological parameters for analyzed welding technologies (acc. [11], [12])

Run No.*	Thickness [mm]	Dimension of filler material [mm]	Current [A]	Voltage [V]	Welding speed [cm/min]	Remarks
SAW (butt weld)						
1	8 (*1)	4,0	420 ÷ 450	33 ÷ 35	58 ÷ 65	–
2			530 ÷ 550	33 ÷ 35	60 ÷ 70	
SAW-tandem (butt weld)						
1	10 (*1)	5,0	650 ÷ 670	31 ÷ 32	95 ÷ 110	welding head 1 (*3)
			580 ÷ 600	40 ÷ 41	95 ÷ 110	welding head 2 (*3)
2			600 ÷ 620	31 ÷ 32	90 ÷ 100	welding head 1 (*3)
			550 ÷ 570	40 ÷ 41	90 ÷ 100	welding head 2 (*3)
SAW-tandem (fillet weld)						
1	5 (*2)	2,0	380 ÷ 400	32 ÷ 33	40 ÷ 50	welding head (*3)
1’			400 ÷ 420	33 ÷ 34	40 ÷ 50	welding head (*3)
GMAW-tandem (fillet weld)						
1	5 (*2)	1,6	250 ÷ 270	34 ÷ 36	80 ÷ 120	–
1’			250 ÷ 270	34 ÷ 36	80 ÷ 120	–
FCAW (fillet weld)						
1	4 (*2)	1,2	255 ÷ 260	27 ÷ 28	18 ÷ 24	–

Symbols:
* – Run No. complying with Fig. 4; *1 – Thickness of the plate; *2 – Thickness of the fillet weld; *3 – complying with Fig. 4

Comparing the relations presented in Fig. 3 one can state that:

- the greatest percent share in mass of the sections was attributed to shell plating - it amounted on average to abt.. 58%, and the lowest share – to additional elements: abt. 5% on average (see Fig. 3B).
- there is a linear relation between number of section elements and number of welds (see Fig. 3C). The largest percentage of number of elements was found for 1st order stiffeners (see Fig. 3D): (abt. 37%on average) and additional elements (abt. 44%on average), the smallest percentage - to shell plates (abt. 8%on average). Section No. 19 had the largest number of elements (Fig. 3A), namely 177 pcs. Section No. 1 had the smallest number of them, only 9 pcs.
- the largest percentage of weld length (Fig. 3F) was found for 1st order stiffeners (abt. 53% on average), the smallest (abt. 10% on average) – for additional elements. Section No. 16 (Fig. 3E) had the largest length of welds equal to 935 m. The smallest weld length of 68 m was found for Section No. 1.

ASSESSMENT OF TECHNOLOGICAL USEFULNESS

The assessment of technological usefulness of panel production line was performed on the basis of results of analysis of welding technologies by taking into consideration the so called significant parameters obtained with the help of input parameters to this analysis. Among the significant parameters used for the technological usefulness assessment the following were numbered: labour consumption for welding the sections, welding wire consumption as well as linear heat input of welding process.

All the significant parameters greatly influence operational performance of flow production line of ship hull flat sections and are associated with the notion of producibility of welded structures (see: [3], [4]), i.e.:

- labour consumption for welding the sections is directly depending on duration time of welding the sections and on their masses [6],
- welding wire consumption which was selected as one of the factors of material consumption index [6] and is present in all welding operations of every sequence, directly impacts outlays onto production means.
- welding process linear heat input which, out of the all above mentioned assessment parameters, is most connected (however not directly) with influence on required quality of structure. The heat input is one of the crucial factors of welding process which impacts magnitude of deformations of welded structures, [16] ÷ [18], that makes application of corrective treatments (mainly strengthening operations) necessary. The treatments significantly rise labour expenditure for manufacturing the structures. As estimated, various repair operations done on the section assembly line consume about 30% of all labour amount expended for ship hull structure building [19] (i.e. that comparable with percentage of labour time consumed for hull structure welding in relation to total ship building time [20]).

Results of the performed assessment, grouped into absolute value sets (for all sequences of welding technologies) as well as percentage value sets (split according to particular stands of the production line and used welding technologies) are given in Fig. 5 ÷ 9.

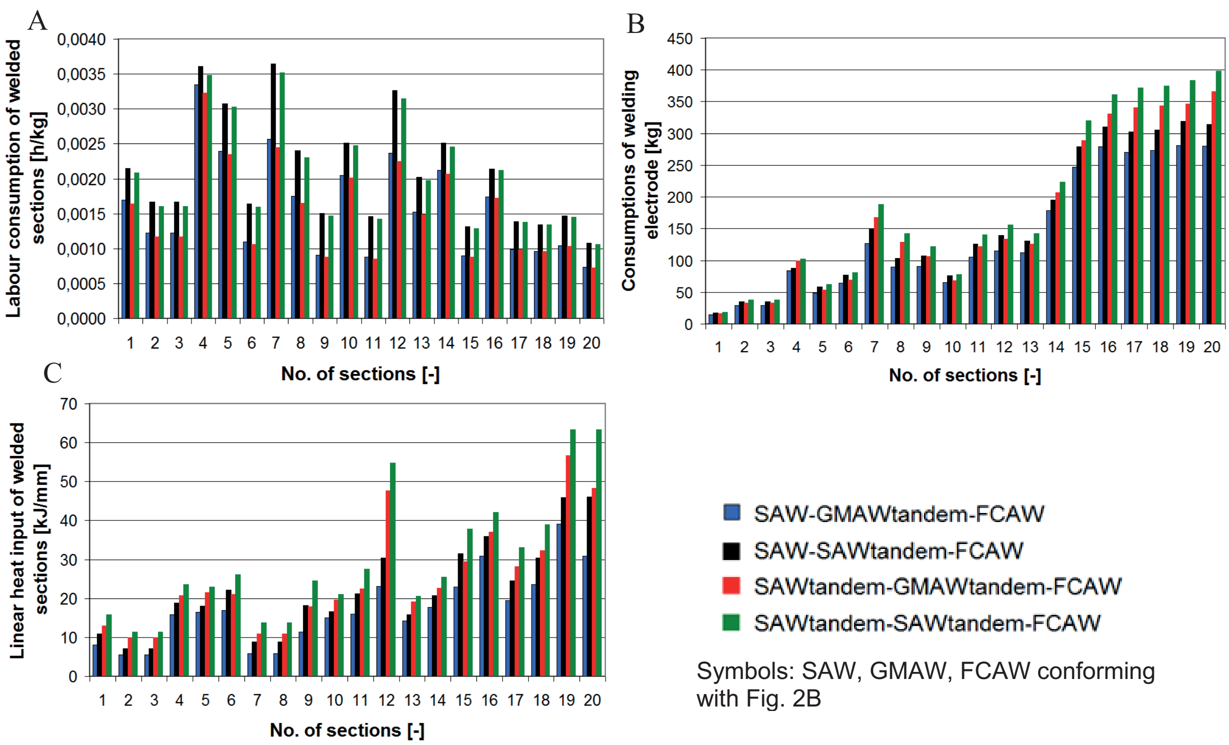

Fig. 5. Sets of absolute values of the selected performance parameters of panel production line, i.e.: A – welding labour consumption, B – welding wire consumption, C – linear heat input, for the assessed welding technologies used on the panel production line

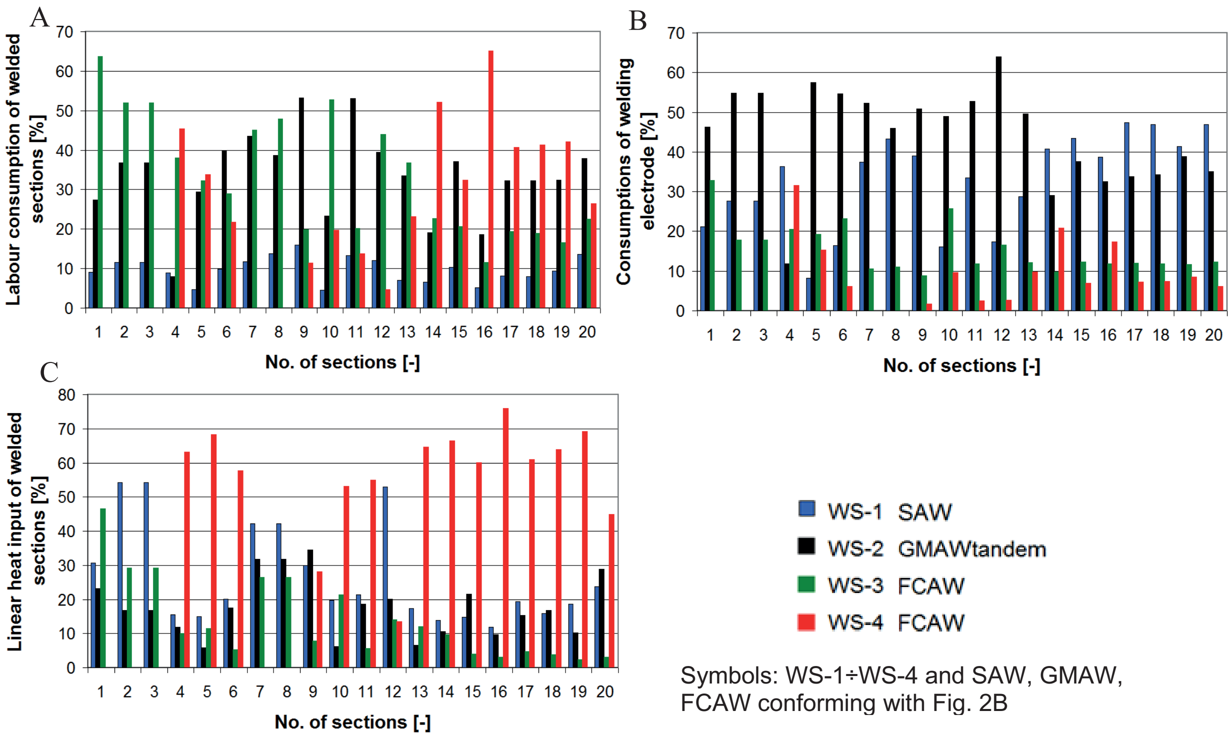

Fig. 6. Sets of percentage values of the selected performance parameters of panel production line, i.e.: A – welding labour consumption, B – welding wire consumption, C – linear heat input, for the particular welding stands of the production line in the sequence: SAW-GMAWtandem-FCAW.

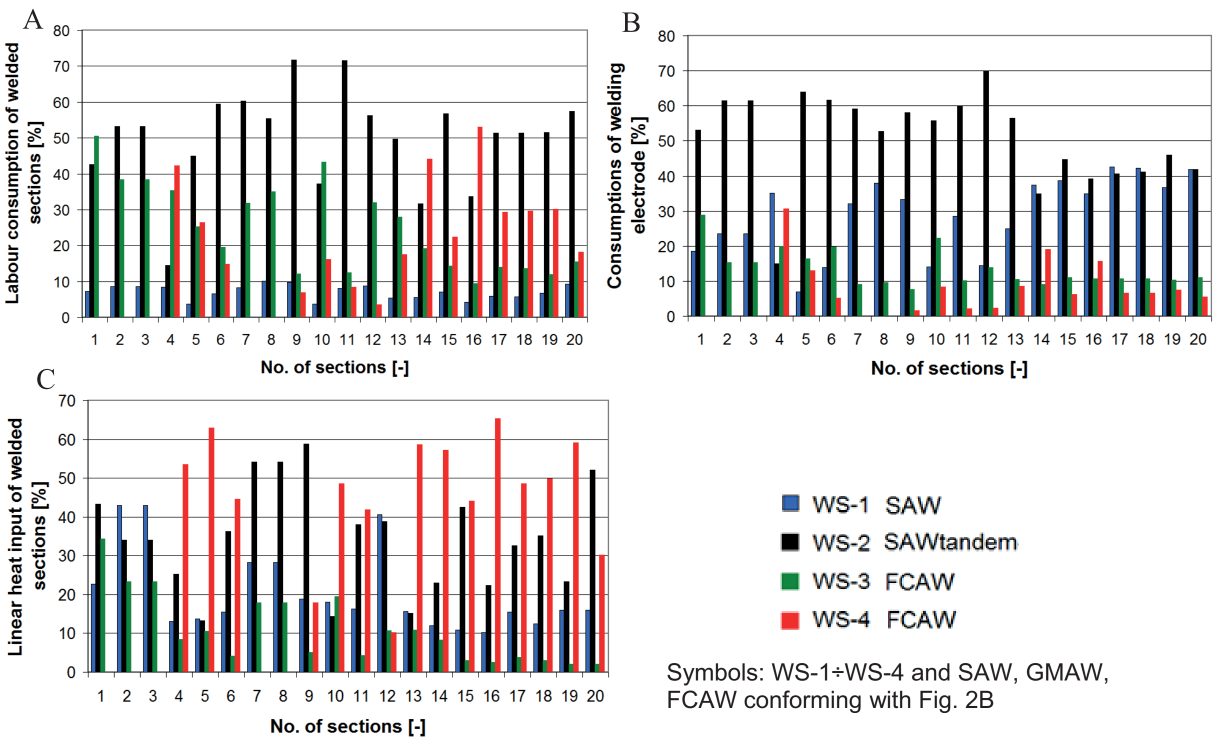

Fig. 7. Sets of percentage values of the selected performance parameters of panel production line, i.e.: A – welding labour consumption, B – welding wire consumption, C – linear heat input, for the particular welding stands of the production line in the sequence: SAW-SAWtandem-FCAW

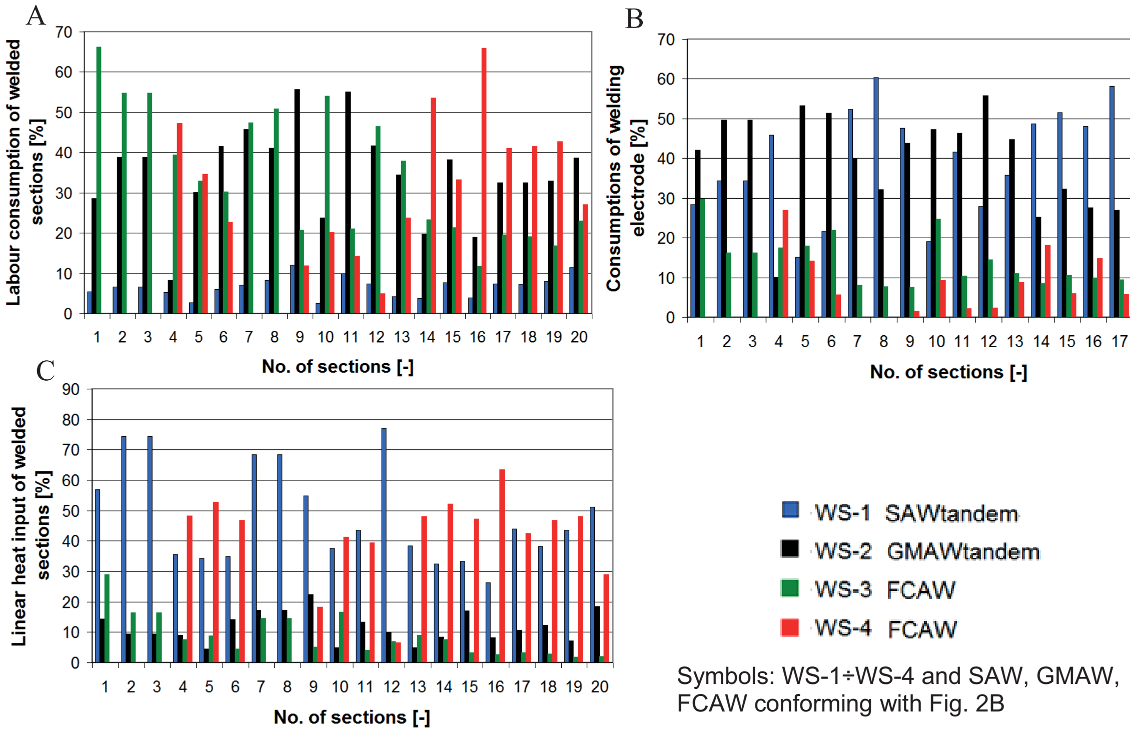

Fig. 8. Sets of percentage values of the selected performance parameters of panel production line, i.e.: A – welding labour consumption, B – welding wire consumption, C – linear heat input, for the particular welding stands of the production line in the sequence: SAWtandem-GMAWtandem-FCAW.

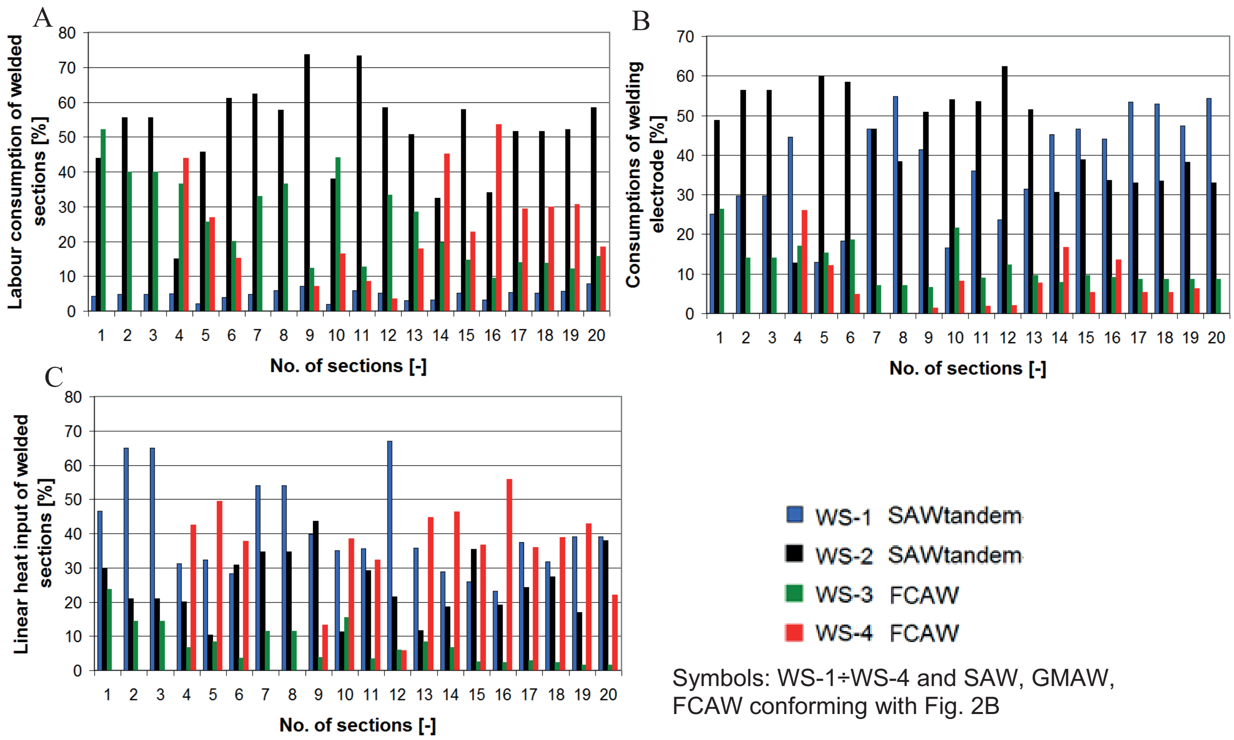

Fig. 9. Sets of percentage values of the selected performance parameters of panel production line, i.e.: A – welding labour consumption, B – welding wire consumption, C – linear heat input, for the particular welding stands of the production line in the sequence: SAWtandem-SAWtandem-FCAW.

Comparing quantitative results of the assessment collected for the assumed sequences of welding technologies, shown in Fig. 5, one can observe that:

- growing tendency of labour consumption values is not dependent on increase of mass of sections (Fig. 5A), whereas growing tendencies of: welding wire consumption (Fig. 5B) and linear heat input (Fig. 5C) do depend on it;
- among labour consumption values (Fig. 5A) two distinct group of sequences can be observed: the first in which only tiny differences between particular systems, i.e. the group with the largest labour consumption values – represented by: SAWSAWtandem-FCAW and SAWtandemSAWtandem-FCAW, and the second group of the smallest values - represented by SAWGMAWtandem-FCAW as well as SAWtandemGMAWtandem-FCAW. In both the groups the average difference between labour consumption values equal to 0,0001 [h/kg], which, in the case of the section of the maximum mass (i.e. 23361 [kg]), would be equivalent to 2,3 [h] of its production time, whereas for the section of the minimum mass (i.e. 1444 [kg]) would be as low as 0,14 [h] of its production time. Therefore it was accepted that in a given group every sequence may be considered equivalent;
- the largest labour consumption values were reached for the technologies sequence: SAWSAWtandem-FCAW, and the smallest – for: SAWtandem-GMAWtandem-FCAW (Fig. 5A). The differences in labour consumption values between the sequences were the following: maximum one of 0,0012 [h/kg] for Section No. 7 and minimum one of 0,0004 [h/kg] for Section No. 4 and 14÷20, which in the case of Section No. 7 (having mass of 6000 [kg] and weld length of 717,3 m) is equivalent to 7,2 [h] difference in the section's production time. The generally largest value of labour consumption was noticed in the case of Section No. 7 (i.e. 0,0036 [h/kg]), the smallest – for Section No. 20 (i.e. 0,0007 [h/kg]);
- the largest values of welding wire consumption as well as linear heat input were found for the technologies sequence: SAWtandemSAWtandem-FCAW, whereas the smallest ones for: SAW-GMAWtandem-FCAW (see Fig. 5B and 5C);
- the differences between the above mentioned sequences of technologies in welding wire consumption increase most distinctly in the case of the sections with the largest mass values (see Fig. 5B). The differences amount to: 3,5 [kg] at the minimum (for Section No.1), 118 [kg] at the maximum (for Section No. 20), the average difference amounts to abt. 47 [kg],
- like in the above discussed case, the differences in linear heat input values are as follows (see Fig. 5C): 5,77 [kJ/mm] at the minimum (for Section No. 2), 32,5 [kJ/mm] at the maximum (for Section No. 20), the average difference was equal to abt. 12 [kJ/mm].

Moreover, comparing the percentage values resulting from the assessment which were split into particular welding stands of the production line, shown in Fig. 6 ÷ 9, one is able to observe that:

- the largest labour consumption values were achieved on WS-2 stand for the sequences using SAW-tandem technology (see Fig. 7A and 9A); the values amounted on average to abt. 50% of the total welding labour consumption. However for the same sequences the average total labour consumption on WS-3 and WS-4 stand amounted to abt. 40% only;
- the situation is different in the case of the sequences using GMAW-tandem technology on WS-2 stand (see Fig. 6A and 8A), for which the average labour consumption values are the same as for WS-3 stand and equal to over 30%. Whereas the average total labour consumption on WS-3 and WS-4 stands amounts to abt. 60% for the cases in question;
- the smallest labour consumption values were obtained on WS-1 stand for all the technologies sequences (see Fig. 6 ÷ 9), which amounted on average to abt. 10% of the total labour consumption;
- the percentage values of welding wire consumption are obviously largest for automatic technologies, i.e. those used on WS-1 and WS-2 stands (see Fig. 6 ÷ 9), where they amounted on average to abt. 80% (of total value);
- values which are crucial from the point of view of impact of linear heat input on to post-welding deformations were obtained for the stands on which long continuous welds are made, i.e. WS-1 and WS-2 stands (see Fig. 6 ÷ 9). Hence, on the stands, especially on WS-2 one, one can expect largest deformations which directly impair quality of structures. Admittedly, in some cases (see: Fig. 6C and 7C), the average linear heat input values (on the level of 40% of their total values) were obtained on WS-4 stand, however it should be remembered that on this stand welds really in large number, but short ones, is produced. Moreover, in this final stage of prefabrication the sections reveal rather high stiffness and much lower tendency to deformations than in the initial stages of the process.

On the basis of the presented results (see Fig. 5) as well as conclusions drawn from them it was stated that the most favourable sequence of welding technologies was the following: SAW-GMAWtandem-FCAW (see Tab. 1). The remaining sequences take positions in the order shown in Tab. 1, forming this way a hierarchy of welding technologies sequences from the point of view of their impact onto producibility of welded structures.

Similarly, on the basis of an analysis of the results presented in Fig. 6 ÷ 9, a hierarchy of welding stands was made from the point of view of their impact onto the production line performance (effectiveness).

One of the crucial conclusions resulting from the analysis was that the largest drop in capacity of the production line was caused by semi-automatic welding processes carried out on the stands: WS-3 and WS-4 (see Fig. 2A and Tab. 1). This is most clearly seen when the total labour consumption values obtained for the stands are taken into account; the values may be equal to over 60% of the total labour consumption for welding the sections. Therefore the above mentioned stands are the least efficient areas in the entire production line, whereas WS-1 stand is the most efficient.

For that reason the following proposals dealing with improvement of the performance (effectiveness) of the flow production line, have been offered:

- a conventional solution consisting in an increase in number of the stands for semi-automatic welding (i.e. those for welding 2nd order stiffeners and stiffening-up elements),
- an innovative solution consisting in installation of a gantry fitted with highly efficient devices (e.g. articulated robots) for supporting the welding operations on the stand intended for the welding of 2nd order stiffeners.

Following the performed analysis one may assume that e.g. the doubling of semi-automatic welding stands in number will shorten duration time of welding operations by a half at least. However worth remembering that final result of improvement of producibility of the production line will depend in large measure not only on capacity of used facilities, e.g. robots, but first of all on the obeying of an assumed comprehensive technological regime of welding. Analysis of all the above mentioned aspects will constitute an object of future research projects to be conducted by these authors.

CONCLUSIONS

This paper showed that on the basis of technological – constructional parameters of prefabricated sections and technological parameters of welding processes it is possible to make an assessment of flow production line. As the performed analyses indicated, by appropriate selection of significant parameters it is possible to show their impact onto selected aspects of producibility of welded structures.

The presented approach to this issue, based on analysis of significant parameters, may be applied to any conceptual variant of production line for flat sections of ship hull. Moreover, it was indicated which of the assumed sequences of welding technologies and which of the prefabrication line stands are whether the most or least effective. However it should be remembered that, to make full assessment of technological usefulness of a production line, also analyses connected with assembling and corrective operations as well as with economics of processes should be taken into account so as to increase assessment objectivity as much as possible.

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