Challenges of manufacturability and Product Data management in bending

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Abstract

Effective production in networking environment of sheet metal products needs accurate and relevant PDM (Product Data Management) data, appropriate modelling of components supported by local and global network solutions and utilization of advantages of feature based modelling. To enable these aspects of effective production in sheet metal production it is necessary to evaluate the integration of DFMA (Design for Manufacturing and Assembly) and PDM data. This paper aims at identifying the challenges of DFMA and PDM integration through recognizing possible malfunctioning parts of their integration. The observations are based on sheet metal specimens in which the DFMA and PDM aspects are visible in punching and bending. Moreover, this study will focus on five issues, which are included either in DFMA or PDM data or both: effects of different calculation methods for the flattened length, utilization viewpoints of global or local manufacturability guidelines, assembly conditions, options to tune the manufacturing process instead of changing the product geometry and possible additional requirements given by the customers. Based on practical design and manufacturing tests of sheet metal products, it has become evident that one option to improve the quality of analyzed sheet metal parts is to further develop the integration of DFMA features with the workshop's cutting and punching parameters. As one possible improvement to these kinds of integration tasks of DFMA and PDM data it is suggested that the responsibilities for developing DMFA and PDM applications with proper design parameters could be analyzed deeper between persons working with information exchange, product design, software design or production machine design.

Keywords: PDM data, sheet metal, DFMA, flattened length, Oehler method

1. Introduction
Product Data Management (PDM) is a system that is widely in use in the design and manufacturing industry. The principle of the system has been the same since its development in the early 1980s: managing created data. [2, 3] The created data has to be stored for later use: the data can be reused when designing new structures or when modifying structures during the manufacturing process. A company's designing software is normally linked to a PDM system to guarantee that all the created data and documents are stored in one place. [2, 4] Physically, the databases can be located in different countries and/or in different distributed databases. PDM's important feature is to share information between its users: subcontractors, manufacturers and purchasers. PDM-system helps to organize the data, that the data is in the right place at the right time. [5]

During and after the designing process, the designs (drawings and related data sheets) are saved in to the PDM system. The same PDM system should also be used in the manufacturing plant, so that the drawings are automatically transferred to production. The challenges of manufacturability and PDM can be analyzed by utilizing the triangle in Fig. 1. The three different points of view are information exchange, business, and the technology. From the information exchange point of view, the PDM system makes sure that all needed documents (needed data sheet and drawings) are transferred from the designing unit to the manufacturing unit and vice versa. From the technical point of view, the PDM system is seen as storage for CAD (Computer Aided Design) files (and other design-related files), and in this storage the CAD file formats are revised to a general format (such as PDF (Portable Document Format) to make sure that everyone can see the documents without having the native design software. From the business point of view, the PDM is seen as a business tool and with the help of the PDM system, the benefits of the different units can be measured (statistical information).

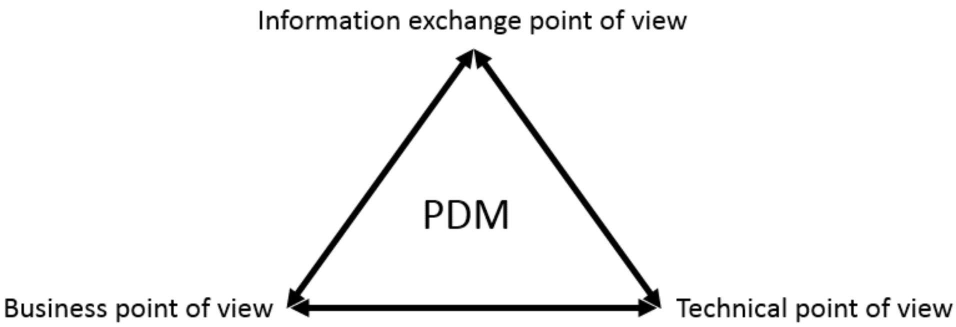


Fig. 1. Three points of view in PDM.

The triangulation model in Fig. 1 should be tuned into a tetrahedron, which is presented in Fig. 2. In this new model, the base of the tetrahedron describes the problems, which are visible mainly during the design stage of a sheet metal product. Used machines are related to the quality of final product, without the machine information (for example tool information), the PDM data cannot be fulfilled. The head of the tetrahedron illustrates the integration of the three corners, showing the aspect of design with practical production and manufacturability aspects in the workshop. The theoretical PDM environment is at the base of the pyramid and the practical level is reached at the top of it. This is interesting as should there be any mistakes in the PDM data, they can be fixed at the production stage (top of the tetrahedron). However, if the PDM system itself works properly, the integration between the base and the top of the pyramid should be perfect, which means that relevant PDM data can be conveyed directly from the PDM system to the production equipment. Without the top of the pyramid (and co-operation between designing and manufacturing) the information cannot be straight converted to machines, and this is the main difference between the traditional points of views (Fig. 1) and tetrahedron points of views.

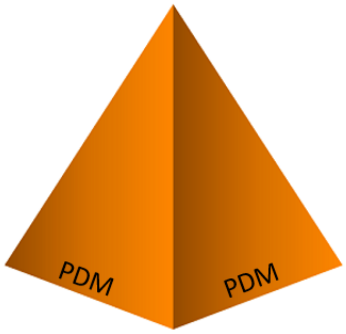


Fig. 2. Tetrahedron of PDM from designing to manufacturing.

Figure 2 shows how complicated the philosophy of fully utilizing PDM systems can be. On the other hand stakeholders, it is in this case, human beings working as software vendors or production machine designers are trying to provide and fulfill the PDM database with appropriate data for sheet metal production according to their best knowledge and experience. Of course, both of these stakeholders might have different values for different bending parameters based on their experience, which could directly lead to some problems during the manufacturing. However, on the other hand, different feature based facilities of design software applications, are utilized during the design phase of the product. If the designer of the sheet metal product trusts in the results given by the prebuild features of the software, the design phase of the product might lead to the product, which is no more appropriate. Automatic features might also suggest optional geometries or dimensions which might work only with some production machines and designer might not have enough knowledge to pick up the right one. So the problem might rise up due to the computer aided information change between the PDM data and feature based design facilities of the software without any relevant signal to the designer that there might be some problems during the production. Unlike often assumed, the problems of getting and using appropriate bending data starts already during the design phase of the product, not only until during the production. Figure 2 illustrates this multilevel problem, which is the important starting point of this research.

2. Methods

The formal approach of different viewpoints of PDM is presented in Fig 1. Based on authors' tentative research results it has already been shown that two real sheet metal products, which originally should have been similar, can differ from each other after production due to the recognized contradictions between DFMA and PDM data [1].

The analysis of feature based modelling in networking environment of sheet metal production has risen up three main viewpoints for discussion [1]: 1) PDM data needs suitable pre- and after-filtering to increase the reliability of manufacturing, 2) effective modelling of sheet metal components should be supported by local and global network solutions and 3) there is the need to utilize advantages of feature based modelling more effectively in a networking environment of sheet metal components[1].

Therefore, in this paper, it is justified to continue this study and present dimensional values to evaluate the quality of these kinds of sheet metal products and especially to recognize the malfunctioning part of DFMA and PDM data integration.

The goal of this paper is to focus on five (5) research questions as follows:
(1) What is the difference between different calculation methods for the flattened length of the sheet metal component?
(2) With regards to the guidelines for sheet metal products bending, should they follow the global (general rules) or local (restrictions due to tooling at workshops) guidelines?
(3) Where should the focus lie in regards to manufacturability aspects: on separate components or on the assembly? Between these two viewpoints there are contradictory aspects. How can they be clarified and added in to the product's PDM data?
(4) What should be done if the amount of manufactured products increases: improve the products' manufacturability or modify the manufacturing process?
(5) If the customer has new requirements and the product's material has to be changed, is the manufacturing process also modified?

3. Application

In this paper the observations of possible contradictions of DFMA and PDM data are based on studying specimens in which the DFMA and PDM aspects are visible in punching and bending. So far the intention has been to point out would it be possible that there might be some mistakes in DFMA and PDM integration [1] but in this study the application goes deeper into the reasons of the integration problem. The DFMA rules can be applied either locally or globally. Depending on the available sheet metal machines and tools at the local workshop, the local requirements might differ from the general (global) DFMA rules, for example in the case of geometries that are allowed when designing/manufacturing box-shaped geometries: the edge radius, the sizes of the shoulders, the manufacturing accuracy, and tolerances. Later on, the same differences might be faced in the CAD environment; that is, if the general rules are used in the PDM system instead of the specially tuned local DFMA aspects used in said workshop.

If the challenges of integrating DFMA and PDM data are local and if they are mostly based on difficulties in deciding who should do the practical updating work in the company, the use of a so-called RACI matrix is recommended to divide the tasks within the company [6]. The RACI matrix assigns who is Responsible, Accountable, Consulted and Informed about each task during the updating process. Sometimes several people may be able to handle the updating process but, especially in large companies, no one takes practical action. The RACI matrix can help in establishing who should do the job and when.

The basic hypothesis in DFMA is that the designers know what kind of tools and machines are in use when they make the designs. The main idea of DFMA is to integrate design and manufacturing units. Therefore, the integration concerns the products and production: one traditional approach is to presume that design changes should not occur during the manufacturing process. To save money and time, the changes in design should occur at an early stage of the design process. [7] However, it should be noted that even if the manufacturing process is easy, it does not mean that the assembly is as well [8].

In contrast to this traditional viewpoint, the opposite approach is to alloy quick and easy changes to the product geometry at the beginning of the production or even later to make manufacturing more suitable for the local workshop. In fact, in past decades, different approaches have been developed to support the interaction between design and manufacturing, such as concurrent engineering, collaborative design or the least commitment philosophy. In addition, there have been attempts to apply the principles of operational analysis. For example according to [9], "the cost of using delayed differentiation strategy is important to the manufacturer during product customization. In addition to the customer demand, this cost interrelates with other factors such as the supplier lead time delivery window, the supply of raw materials and the inventory levels at the beginning of the manufacturing process." No matter which one of these methods, approaches, philosophies, or analyses are examined, the key issues are the consistency of knowledge in the modeling framework [10] and the effective use of the existing PDM system.

One concrete example is illustrated in Fig. 3, which shows one challenge when integrating general and local DFMA-rules to support the existing PDM system (figures on the left and the middle). Right sid of the Fig. 3 shows that the available tools play a key role in guiding the DFMA-aspects: if tools are not known by designer, the manufacturing of the part may be impossible. According to the general DFMA rules, box-shaped sheet metal geometries that are too closed should be avoided (in Fig. 3 in the middle: see the condition $e_2 > e_1$). This is to ensure that the local restrictions at the workshop are added to the PDM system and to enable the full utilization of this data in the CAD environment. To do this, the limitations of the minimum and maximum sizes of the sheet metal component should be established. Typically, if the subcontractor is changed, this data should also be updated. In this case, changing the manufacturing machine is not a reasonable solution, which means that either the product geometry should be changed or a new subcontractor should be sought. [11] However, the question still remains as to who should update the PDM system and the feature based design data, including this local restriction, as well as the list of possible subcontractors and their facilities.

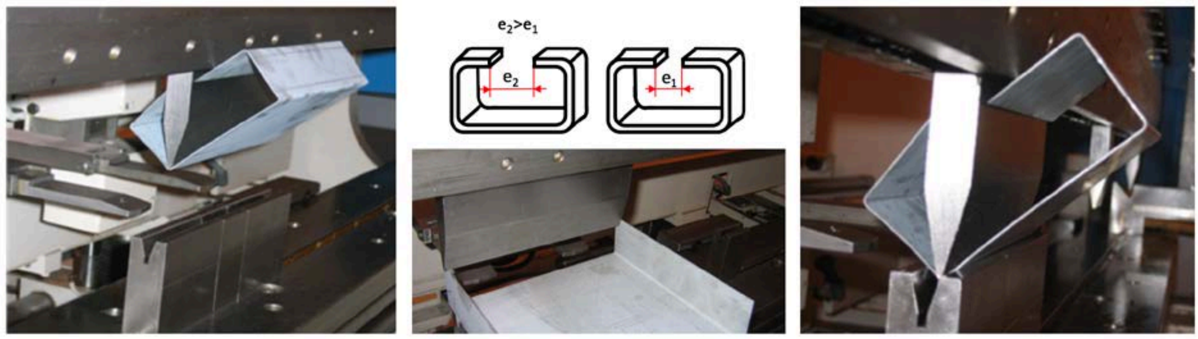


Fig. 3. The available tools play a key role in guiding the DFMA-aspects. [11]

The second example is presented on the right side of Fig. 3. In this case, the desired geometry of the sheet metal component is easy to model, and usually the design wizard gives no warnings during the design process. However, a practical local problem encountered at the workshop might be missing tooling for the required bending depth and corner size. In this case, the design rules for bending might be fully correct in the PDM system and in the CAD environment, but the main problem is that the suitability of the existing tooling has not been checked with the workshop. The question in this case might be whether it would be wise to change the geometry of the product or buy the required tools. Certainly, the answer depends on the number of products to be manufactured. Therefore, once again, the question arises as to how to update the PDM data and who should do it?

The examples in Fig. 3 could be seen only as poor design of geometry, insufficient analysis of available tools or machine properties, or a starting point for manufacturing more complicated sheet metal products. If the example is widened in the direction of the illustration in Fig. 4 (example made with SolidWorks), it can be noticed that if the task is to manufacture a closed box with a tight cover, the positioning of the bend edge becomes critical. At least when the cover is placed over the box. Therefore, one part of the product data is the positioning of the bend line and the bend edge.

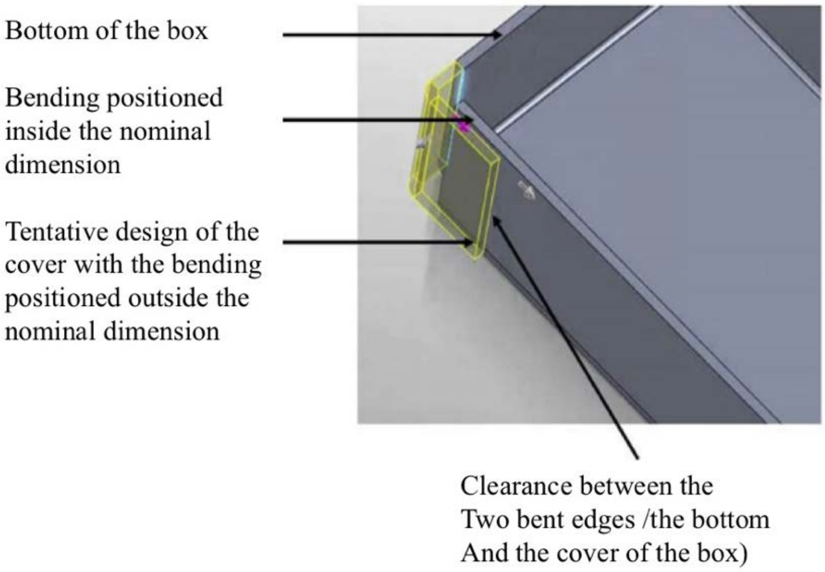


Fig. 4. DFM (Design For Manufacturing) aspects becomes DFMA aspects when designing a box with bottom and cover.

The example in Fig. 5 presents a part of a principal sheet metal component, which includes both a bent geometry and a cut groove. If this groove is the hole into which some additional components are assembled as regards the sheet metal part itself, or if the groove is an opening to lead cables or wires into the enclosure, the importance of assembly factors is faced again in addition to the general manufacturability aspects of a bent metal part. The positioning and the dimension of the groove become critical for the assembly stages. The position of the groove depends on the bending accuracy combined with the cutting accuracy, which are both typically handled with the relevant product data. In addition to the DFM aspects of cutting and bending, the DFMA aspect related to the manufactured groove also becomes evident (Fig. 5 circled in red in the SolidWorks model and its flattened geometry). Even these simplified examples provide enough evidence that the product data (PDM data) should include not only the information dealing with separated manufacturability aspects of sheet metal components, but also data on integration with the assembly stages. If the parts of a large assembly are manufactured globally, the key issue is to ensure that the designers are aware of their responsibility for deciding who takes care of the assembly aspects and how the information is integrated into the product data.

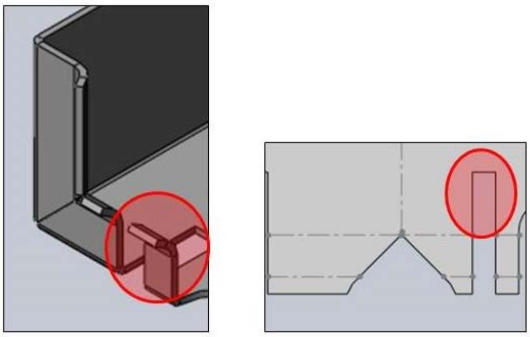


Fig. 5. Critical positioning and dimensions of the groove.

The important connection with DFM and DFMA has been pointed out e.g. in [12]. According to [12] “In cases where sheet metal components were designed as part of an assembly, or whenever individual parts need to undergo further location specific operations, such as, e.g. seam welding, tolerance problems can indeed form a justified reason for part rejection.” The two examples presented in Fig. 4 and Fig. 5 supported by [12] oblige manufacturers to pay considerable attention to the correct way to express the relevant PDM data of a sheet metal component in the product database. Because the connection between DFM (e.g. bending or cutting) and DFMA is clear, it is important that all designers know exactly what design parameters have been used and how they were used during modeling. However, this is problematic for many reasons. To ensure the effective use of PDM data, it should be clear how e.g. the bending geometry has been modeled and especially how its flattened geometry has been calculated or estimated.

In SolidWorks there are three optional ways to select the bending parameters to form the final geometry of a sheet metal component. One option is to combine these parameters with the selected material and then calculate the length of the bending edge by utilizing standardized formulas. The other option is to utilize K-factors (the ratio of the neutral axis to the material thickness). The third option is to collect bending data into a SolidWorks database, which includes different materials, different sheet thicknesses and corresponding K-factors, which are verified at specific workshops and bending machines. This third option offers one possible solution to the challenges of integrating DFMA and PDM data in practical design work. However, a great deal of manual work is required to compile the database. Nevertheless, if that database exists it would be relatively easy to write software code to combine the modeled bending geometry, the name of the intended workshop for manufacturing, and the bending parameters of the product based on the properties of the bending machine at the workshop. In fact, this code could be added to the Excel-based workbook which is functioning behind the SolidWorks feature modeler. These bending parameters will replace the original parameters which SolidWorks typically includes in the modeled sheet metal component if the designer uses the preset values. This means that the PDM system should include the wizard which is able to integrate and filter the PDM data in the described manner.

The practical example (Fig. 3) also shows how difficult it is to ensure that the PDM data which is used globally actually includes the particular data which should be used to ensure that both DFM and DFMA aspects of a sheet metal component are, in fact, taken into account. One of the problems, based on the previous example, is that several data sheets may be available for the same sheet metal geometry; therefore, special attention is required so that the right data is connected with the model and its PDM data. The complexity of selecting the most effective way to describe bending parameters in PDM data has been presented in this paper.

It can easily be understood that the manufacturability aspects of the DFMA example in Fig. 3 would essentially change if, for example, the manufacturing process is changed from manufacturing several sheet metal parts to pressing or forging processes. The DFMA rules in this case will change considerably.

When the manufacturing process is changed, the information that has changed also has to be updated in to the PDM system. Manufacturing processes may also change when the company makes the decision to go global. Despite these changes, the designers are still able to use the so-called rules of thumb; this will make the design process easier. Rules of thumb are based on earlier experiences, but they do not guarantee that the design will be manufacture-friendly [13]. CAD software is normally integrated into the PDM system to make sure that the drawings and documents are easy to save in the PDM. After the implementation of PDM (and integration to CAD software) it is crucial to update the system to correspond to the company’s needs and, for example, the used materials.

Globally, knowledge concerning the use of machines and tools is a challenge: it is well known that designing may occur in different locations than the actual manufacturing. In addition, the subcontractor may change occasionally and the information about this change may not reach the designers; they may still design parts for the machines that were used by the previous subcontractor. Many factors must be taken into account when designing sheet metal products, such as material properties (e.g. mechanical and chemical properties), strain bounding criteria (e.g. tearing, wrinkling and roughness), and process parameters (e.g. strain rate, temperature and lubrication). It is therefore, obvious that not only do the machine types have to be known, but also the material properties have to be available for the designer. Moreover, it is not sufficient to know the material properties from one batch: the material properties may vary between different batches. [13]

The PDM system and CAD software are already integrated together in order to ensure that the created information is in a safe place. However, in the future, an integration between the DFMA and CAD (also including the PDM) should be possible. With the help of this integration, it should already be possible to eliminate manufacturing errors during the design process. Some research about this integration has already been done [8, 11], but more is needed, such as how the DFMA aspects can actually be integrated into CAD and what this requires from the PDM system. It is clear that in the PDM system the information has to be classified; this also helps the users to find the necessary data from the system.

3.1 Analytical evaluation of the flattened length
Two different methods were compared when the flattened length was calculated. Simulation was done with SolidWorks, where specimens were modelled. It was notice that differences exist when using two methods: DIN (Deutsches Institut für Normung) and Oehler. Two different test were done: in the first test the sheet thickness was 3 mm and in the second test the sheet thickness was 2 mm. On both cases three different radiuses were used and flattened length was measured after the use of these two different methods. The simulations were performed as shown in Fig. 6 with two different materials being compared: the materials were a hard material (stainless steel 1.4509) and a soft material (aluminum 5061). The used bending method was air bending. Results are listed in table 1 and percentage differences are shown in Fig. 7.

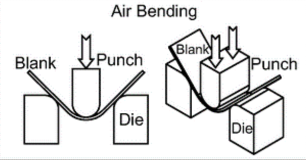
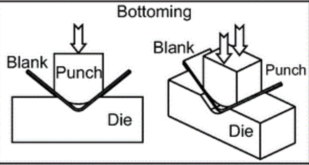
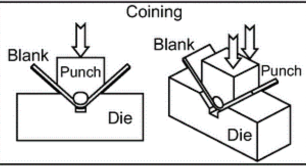
Bend Process	Ratio R/T	K Factor by Material "Type"...		
		Soft	Medium	Hard
Air Bending 	0 ~ 1	0.33	0.38	0.4
	1 ~ 3	0.4	0.43	0.45
	> 3	0.5	0.5	0.5
Bottoming 	0 ~ 1	0.42	0.44	0.46
	1 ~ 3	0.46	0.47	0.48
	> 3	0.5	0.5	0.5
Coining 	0 ~ 1	0.38	0.41	0.44
	1 ~ 3	0.44	0.46	0.47
	> 3	0.5	0.5	0.5

Fig. 6. K-factor's influence in the bending process [14]

Table 1. Comparison of the flattened lengths when using DIN and Oehler methods.

Sheet parameters		Hard Materials: K-factor = 0,45				Soft Materials: K-factor = 0,40			
		Flatten pattern (mm)		Difference		Flatten pattern (mm)		Difference	
Thickness	Radius	Oehler	DIN 6929	Absolute	%	Oehler	DIN 6929	Absolute	%
3	3	130.83	130.24	0.59	0.45 %	130.60	130.24	0.36	0.28 %
3	2	131.26	130.47	0.79	0.60 %	131.03	130.47	0.56	0.43 %
3	1	131.69	130.54	1.15	0.87 %	130.46	130.54	0.92	0.70 %
2	3	130.13	129.87	0.26	0.20 %	129.97	129.87	0.10	0.08 %
2	2	130.56	130.16	0.40	0.31 %	130.40	130.16	0.24	0.18 %
2	1	130.98	130.36	0.62	0.47 %	130.83	130.36	0.47	0.36 %

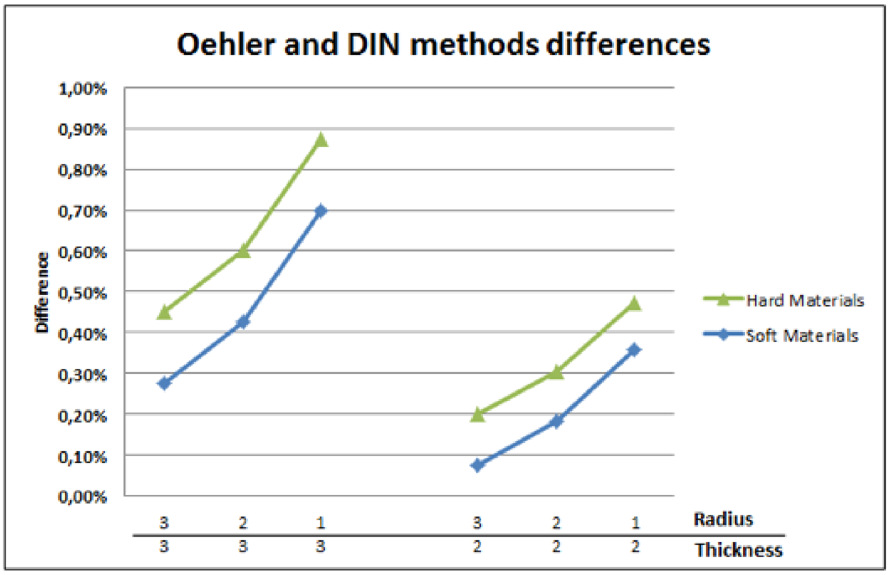


Fig. 7. Flattened lengths percentage differences when using DIN and Oehler methods and two different materials.

When analyzing Fig 7 and table 1 it can be noticed that DIN and Oehler methods tend to converge (difference tends to zero) if :

- The bend radius is increased while thickness is constant (less severe bending).
- The thickness is low.
- The material is soft.

Differences between DIN and Oehler tend to increase when bending conditions becomes more distinct.

3.2 Tested and measured specimens

In Fig. 8, the authors present two specimens which differ from each other due to the following bending parameters. The specimen A was bent by placing the border line exactly on the theoretical midpoint of the pending radius. Specimen B is otherwise the same, but the border line is moved by using an offset with the magnitude of the sheet thickness.

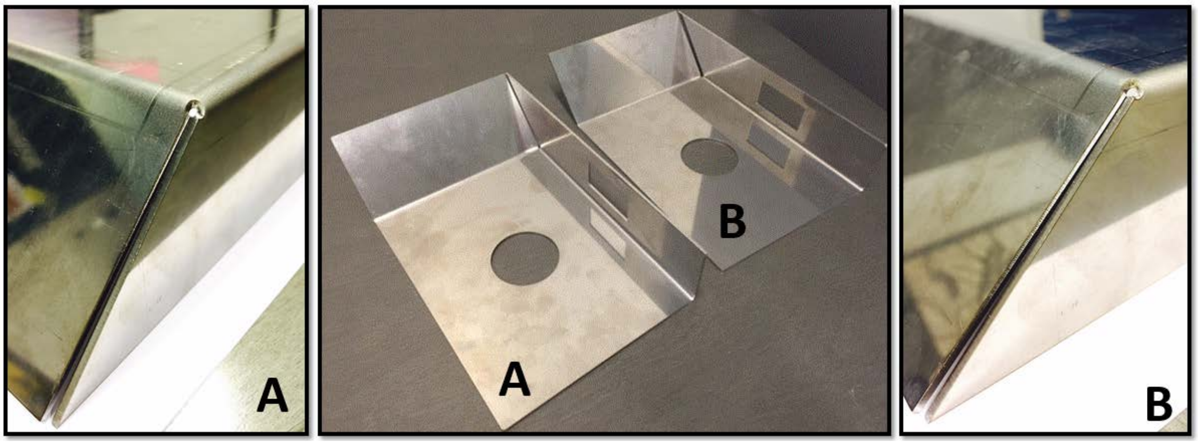


Fig. 8. Two different specimens.

The specimens were cut from a metal sheet with turret punch presses, and at the same time the holes were cut. The nesting was done by JetCAM (Computer Aided Manufacturing) software, which automatically created the relief to the bent corner. The material used was stainless steel 1.4509 and the thickness of the sheet metal was 2 mm. The flatter pattern and the final dimensions are shown in Fig. 9.

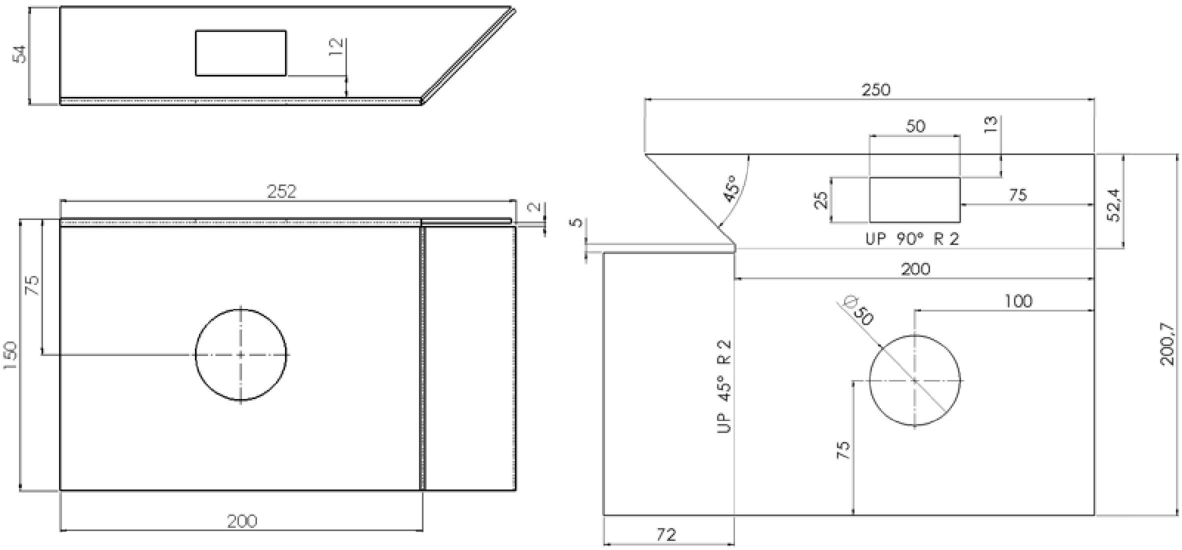
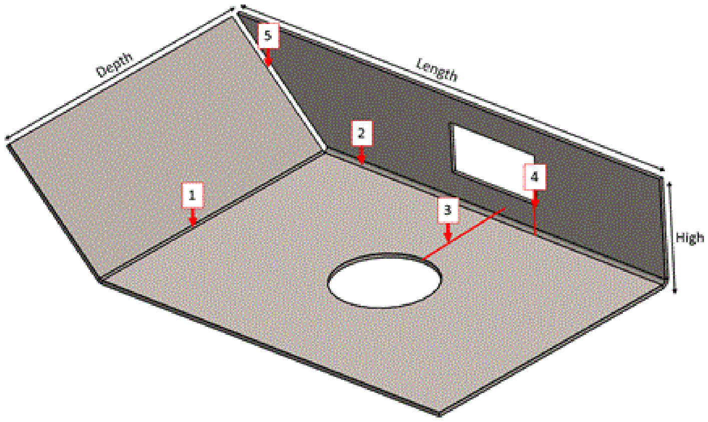


Fig 9. Specimen's final dimensions and flatter pattern.

After the cutting process, the parts were bent with the NC (Numerical Control) press brake. The tools were selected according to the desired angles. Because the drawing indicated no specific bending radius, the radius was selected to be 1 mm. The lower tool was a V-die with a shoulder width of 200 mm. The bending method used was air bending, and based on material properties (the thickness of the sheet and the material), the machine controls were selected. Table 2 shows the main observations in product quality.



Comparison criterion	Specimen A	Specimen B	Theoretical dimensions
Sharpness and accuracy of bend corner 1	44.8°	44.9°	45°
Sharpness and accuracy of bend corner 2	89.7°	89.5°	90°
Position of square hole	11.7 mm	9.9 mm	12 mm
Position of round hole	52.1 mm	54.1 mm	50 mm
Relief	0.05 mm ja 1 mm	1.7 mm ja 2.7 mm	2 mm
Outside dimensions Depth Length high (right/left)	 152 mm 251.5 mm 51.7 mm / 50 mm	 154.4 mm 251.1 mm 49.9 mm / 50.9 mm	 150 mm 252 mm 54 mm / 54 mm

Table 2. The main observations in specimen quality.

4. Results based on analytical calculations and specimens

The earlier FAIM conference paper [1] showed three types of contradictions within the DFMA process. When these three contradictions are conveyed to the form of a research questions and compared with the analyzed specimens, the following answers were recognized. The first question was what is the difference between different calculation methods of the flattened length of a sheet metal component? By analyzing the graph (Fig. 7) and table 1, it can be seen that these two different methods (DIN and Oehler) tend to converge. Three possible reasons for this convergence include low sheet metal thickness, a soft material, and the fact that when thickness is constant the bend radius increased. Differences between DIN and Oehler methods seem to increase when bending conditions become more distinct.

Second, in regards to guidelines for sheet metal products' bending, should the global (general rules) or local (restrictions due to tooling at workshops) guidelines be followed? As shown with specimen A and B, which were bent based on local production parameters, neither of them made the set requirement of original design presented in Fig. 9. After the first bend of 90 degrees, it was recognized that the used force was not enough: the angle was 4.5 degrees too small (angle was measured to be 85.5 degrees), so the machine was setup again.

Thirdly, where should the focus lie when thinking about manufacturability aspects: in separating components or in the assembly? As these specimens show, both of them suffer from malfunctions during the assembly stages because both the bend edges and the holes are in the wrong position. The positioning of the squared holes was -0.3 mm (A) and -2.1 mm (B) and with the rounded holes 2.1 mm (A) and 4.1 mm (B). Compared with the variation of outside dimensions (variation between 0.9 to 4.4 mm), this makes assembly almost impossible.

The third question's sub-question concentrated on how contradictory aspects between these two viewpoints can be clarified and later registered in the product's PDM data. The PDM data should include the guidelines the designers had in mind. Because every designer thinks differently, it is crucial that the specific guidelines for each machine have been defined in the PDM data. The PDM data contains all the necessary information, for example, on how the bending should take place according to the material and also where exactly the bending should be done. In addition, the PDM data should include specific information about the machine tool and tools used. The PDM data easily suffers from contradictions between global and local rules and the data should either be provided with certain design conditions or be constructed according to the strictest guidelines of DFMA. This viewpoint is currently important because the business oriented trend is towards locally independent manufacturing or at least distributed production.

As illustrated in figure 2 the main solution to the second and third issue is to ensure that during the design phase of the product, the information exchange between the PDM database and the feature based facilities of the design software would result not only the appropriate geometric and dimensional options but also give guidelines to select either the right production facilities or even some names of possible sub-contractors or workshops who are able to provide the required product quality. The content of the PDM data and its interaction with the design software (information exchange) are in key role.

The fourth question was what should be done if the amount of manufactured products increases; improve the products' manufacturability or modify the manufacturing process? These specimens show that the problem is not the manufacturability itself (bending and cutting are relatively easy), but rather the parameters in PDM data that cause problems in quality. For example, the angular error of bend edges varies between 0.1° and 0.5° and the width of the relief varies from 0.05 mm to 2.7 mm. It is important to observe that the sharpness of the corners in specimen B yields a higher quality than the dimensions of the relief in specimen A. From Fig. 10 it can be observed that the reliefs in both specimens are completely different. The main reason is that the bending has been performed differently: it depends on where you set the punch.

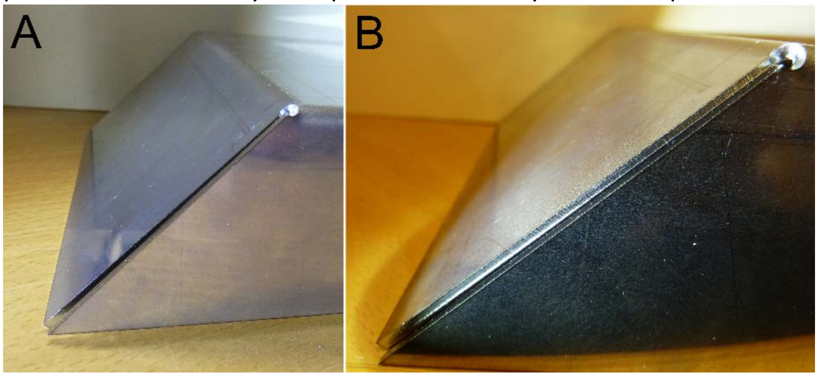


Fig. 10. Specimens' reliefs.

The final questions enquired if, when the customer has new requirements and the product's material has to be changed, the manufacturing process is also modified. The specimens were made out of stainless steel, but the change of the material naturally affects the magnitudes of the bending and cutting parameters.

5. Discussion and conclusions

The problem of updating the PDM data to match the product's real DFMA data has been recognized many years ago. The main question has been who should be responsible for updating: is it the task of software designers, manufacturing workshops, or engineering designers? Even the manufacturability of a simple sheet metal component analyzed in this paper shows the difficulties in utilizing the ready-made DFMA parameters in a common CAD software in perfect assembly conditions. The main reason for the unacceptable quality of the analyzed sheet metal parts was the improper integration of DFMA features with the workshop's cutting and punching parameters. Based on the manufacturing tests, the main dimensions of the bent edge varied up to 26% due to incorrect PDM data (the relief of the open corner, Table 2, item 5).

The comparison with earlier results of scientific research support the findings of this study. Some analogical studies have been made in engineering, e.g. in welding industry where the key issue has been the management of welding parameters in a networking environment. For example in [15] it is presented that it is possible and reasonable to integrate the existing PDM system to the DFMA in a form of the database of welding processes, materials, consumables, standards and guidelines and proper weldment design. Some more general studies have been made in the field of integrating PDM and DFMA data. For example in [16] it has been analyzed how the different aspects of design and manufacturing and assembly could be included in the overall product lifecycle management (PLM) model and what would be the appropriate content of PDM data to support this overall model. In this research PDM module was seen as a bridge above the gap between design and manufacturing. It has also been recognized that during the early stages of PDM system development the design data of sheet metal products was somewhat filtered out to make it fit better for the PDM system content and requirements. In [17] some options have been show how to enable to add DFMA data into the PDM system. In [17] it is also highlighted that there is the lack of knowledge of the typical sheet metal design aspects and basic rules of sheet metal designing.

If the design and manufacturing stages of a product are handled within one company, the challenges to integrate appropriate DFMA data with relevant PDM data can be solved by applying the classic RACI tool. This tool simply shows who is responsible for the task and who is accountable. This ensures that the job will be done. At the same time it is known who should be consulted within the company in order to collect the required DFMA data and who to inform about the results.

The RACI tool described above is not fully suitable for global manufacturing because the business oriented goals might disturb the problem solution. It is difficult to set responsibility or accountability requirements outside one’s own company. In such situations, the PDM software should be able to classify the DFMA data in order of priority to ensure the existence of functional features (e.g. those that guarantee perfect assembly), and further, it should be able to fine-tune the manufacturing parameters to meet the requirements of the utilized manufacturing equipment at the workshop. One solution to these challenges is that the PDM software uses interactive wizards to filter and integrate DFMA data properly.

Another option to address the challenges in integrating DFMA and PDM data properly together is to omit the use of those geometrical features of CAD software which might later cause contradictions with corresponding manufacturing parameters in workshops. Typically, the bending parameters are among these features. A more advantageous way is to collect the required parametrical data into customized design tables and use them as design rules during the CAD modeling of a sheet metal component. Of course, a bit more work is required to collect this data from several alternative workshops, but on the other hand remarkable profits are gained due to the decrease of malfunctioning components during their assembly stages.

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ensures that the job will be done. The next step during the coming studies will be the evaluation of the data flow between each actuator inside the RACI matrix and effects on cost-effectiveness of design and production.

This research will be continued by comparing the contents of PDM databases used in several workshops. The focus of the coming tests would in tuning the feature based facilities of design software to make it possible to automatically integrate the suggested bending parameters directly with the specific workshops. Of course, these tests would open the possibility to start to build an IoT-based cloud service to collect appropriate PDM data at least for limited sub-contractor chains working in the sheet metal business. It would also be possible to integrate different raw material suppliers and their material parameters to this cloud service.

As the final conclusion and based on the analysis presented in this paper, the connections between the different viewpoints of PDM should be modified from a triangle model to a tetrahedron (see Fig 1 and 2). The traditional triangle model integrates the viewpoints of information exchange, technical aspects and business. In the authors' opinion, it would be better to integrate information exchange, product design and software design with support for production machine designers' work.

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