Product Design and Development According to the Project of Equipping the Summer Kitchen and Bar using Sheet Metal Bending Tools

Sandra Bedžeti, Graciela Šterpin Valić, Goran Cukor

***Abstract*—The use of CAD/CAM programs has significantly reduced the time required for designing products, creating the necessary documentation, optimizing machines and creating CNC programs. The paper briefly describes the physical bases of sheet metal forming, then is stated the division of sheet metal forming processes into deep drawing, cutting (shearing, blanking and punching) and bending. In the following is started with modeling of the parts according to the project of equipping the summer kitchen and bar, and description of two modeling principles - bottom-up and top-down. Material chosen for production of the parts is austenitic stainless steel X5CrNi18-10. This is followed by a description of the procedures for 3D modeling of the parts and creating assembly in Autodesk Inventor program, the procedures for creating modeled positions, i.e. nesting, laser cutting and creating a CNC program for bending, and finally assembling and welding with the TIG process.**

***Index Terms* — 3D modeling, assembly, bending, nesting, sheet metal forming**

I. INTRODUCTION

Metals and their alloys are formed into semi-finished or finished products by deformation processes with or without destruction, which changes the shape and dimensions of the product. Deformation without destruction is one of the oldest ways of shaping, and today most of the produced steel, non-ferrous metals and their alloys are processed in this way.

Metal forming are divided into processes for deforming massive (3D) parts such as forging, rolling, extrusion and wire and bar drawing, sheet metal forming processes (2D) such as bending, deep drawing and shearing process and to special and non-conventional metal forming processes such as hydroforming, ultrasonic forming, spinning, thread and gear rolling, etc.

Sheet metal is a semi-finished product made of metal materials with relatively small thickness compared to other measurements. It is most often supplied in coiled strips or rectangular plates of different dimensions. Some of the advantages of sheet metal are: great flexibility, durability (high pressure, corrosion, and heat), replaceability (easier repairs, upgrades and changes), sustainability, etc., so sheet metal is used in the household and various industries such as food, medical, automotive, aviation, etc.

The physical basis of sheet metal forming by deformation and the division of sheet metal forming processes are described in the first part of the paper. Two principles of position modeling - bottom-up and top-down are mentioned. Then follows a presentation of the given project, the project of equipping the summer kitchen and bar. The chosen material for making project elements is stainless steel X5CrNi18-10. The following is a description of the procedures for modeling positions and making assemblies of elements from the project in the 3D modeling program - Autodesk Inventor. In the last part of the paper, the manufacturing procedures for modeled positions are described, i.e. nesting of positions, laser cutting, creating a CNC (Computer Numerical Control) program for bending, and finally assembling and welding with the TIG process is presented.

II. SHEET METAL FORMING

A. Physical fundamentals

Due to external forces, stresses arise within the material that result in deformation, i.e. a change in the position of the atoms in the crystal lattice, which changes the shape and dimensions of the deformed body, while its volume remains unchanged. External forces are resisted by internal forces, i.e. stresses, which prevent the atoms from moving from their equilibrium positions. Depending on the force size, deformations can be elastic or plastic.

Elastic deformation of a solid substance is a reversible process, i.e. when the applied stress is removed, the solid substance returns to its original position. Plastic deformation is a reversible (irreversible) process, i.e. by removing the applied stress, the solid remains permanently deformed [1]. The appearance of plastic deformation is explained by a change in the microstructure of the metal, i.e. by redistribution of atoms that make up the crystal lattice. Metals have a polycrystalline structure, contain several differently oriented crystal grains and have an irregular arrangement of atoms. Irregularities of the crystal lattice can be point, line (dislocations), two-dimensional and volume. Dislocations have been shown to be the initiators of the redistribution of atoms and the cause of crystal planes

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sliding. Accumulation of dislocations creates resistance to the movement of other dislocations, hardening of the metal occurs, characteristic of forming by cold deformation, which is carried out at sufficiently low temperatures to prevent recrystallization and recovery of the structure, which would restore the initial properties of the metal [1]-[3].

Plastic deformation of polycrystalline materials in a cold state results in a directed elongation of the grains in the direction of the intensive flow. Grains elongated in one direction determine high resistance, but low deformability in that direction (anisotropy). Anisotropy is the property of a material to show different physical properties in different directions, and it is not favorable during deformation processing because has an impact on the material flow and the product properties [1]-[3].

B. *Sheet metal forming processes (2D)*

Sheet metal forming processes include deep drawing, shearing, blanking and punching, and bending.

The process used to produce tin packaging, car body parts, various kitchen utensils, tin radiators, ammunition and the like is called ***deep drawing***. Deep drawing is the manufacturing process of forming sheet metal into a one-sided open hollow body. By passing through one or more tools, the sheet takes the shape of the desired product. Put simply, pieces of different cross-sectional shapes are made from a flat plate with a special tool. The most commonly used material is sheet metal with a thickness of about 1 mm, and materials with a thickness of 0.02 mm up to 50 mm can be processed. The process of deep drawing takes an important place in serial production [2], [3]. The deformation takes place using: a drawing punch, blank holder and molding cutter called a die. The blank holder prevents the appearance of wrinkles on the edge of the container, and it is not necessary to use it if the sheet is of sufficient thickness.

Shearing is cutting materials without producing chips**.** Shearing in the technological process often means the preparation of material for further processing. Separation procedures, i.e. shearing are those procedures in which a piece of sheet metal is separated by applying a sufficiently large shear force that causes the cracking and separation of the material, which propagates through the sheet, splitting the material. Sheets are separated by applying two blades of tools placed below and above the plate, in such a way that one can be moved relative to the other. Sheet metal shearing is one of the most commonly used procedures in the process of cutting metal used in production. The process of cutting with blades takes place in three phases:

I. The phase of elastic deformations - during the action of the cutting force, the stresses in the material are lower than the elastic limit.

II. The phase of plastic deformations - the stress in the material is greater than the stress at the elastic limit, and is less than the material's shear strength. It penetrates the metal about 5-40% of its thickness.

III. The phase of breaking the material - the shear strength of the material is equal to the stress value in the material. At the moment of the appearance of the first crack in front of the cutting blade (at the place where the most stress is concentrated), separation of the material occurs [4].

Blanking and ***punching*** are sheet metal forming processes that involve the precise removal of material from the workpiece. The main difference in these processes is in the final product. In blanking, the working material is removed from a larger piece of sheet metal that is discarded as scrap, while in punching, the removed material is discarded as scrap, and the final product is the remaining sheet metal. These sheet metal forming processes are cost-effective for large-scale and mass production [5].

Sheet ***bending*** is a metal forming process without removing chips, where the application of force causes the sheets to bend at an angle and form of the desired shape. The bending process causes deformation along one axis, so a number of different processes are performed to form a complex part. Sheet bending is most often done in a cold state, but in the case of larger thicknesses, the sheets need to be heated [5]. Looking at the cross-section, Fig. 1, it is evident that the metal is compressed in the inner part, it shortens and is loaded with compressive stress. In the outer part, metal is under tension, it stretched and load on the tensile stress. The sheet metal is under the influence of elastic and plastic stresses, which results in the material taking the desired shape and expansion of the material by the cessation of elastic stresses. Bending is characterized by several different parameters shown in Fig. 1.

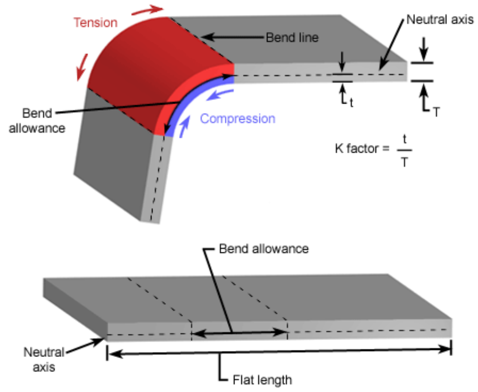

Fig. 1. Sheet-metals bending parameters [6]

The neutral axis represents the boundary line inside the sheet along which no forces act, and accordingly its length is constant. The K-factor (K) is a constant that represents the position of the neutral axis in the material, and it depends on several factors such as the material, the angle and method of bending, etc. It is usually from 0.25 to 0.5. It is calculated as the ratio of the distance of the neutral axis (measured from the inner bending surface) (t) and the thickness of the material (T), or according to the following formula:

$$K = \frac{t}{T} \tag{1}$$

Changes in the length of the inner and outer surfaces are related to the original straight length, i.e. the undeformed length of the sheet (L), using two parameters: Bend Allowance (BA) and Bend Deduction (BD). Bend Allowance represents the length of the neutral axis between the bend lines, i.e. the length of the bend arc. Bend Deduction represents how much the sheet is stretched by bending. The term Bend Deduction is also known as bending compensation. It is calculated as the difference between the lengths of the mold lines and the total length of the flat mold. By bending, the sheet metal enters a state of stress, and by releasing it, it tries to return to its previous state of balance, this effect is called springback, and is an often cause of errors when determining angles. Fig. 2 shows how a sheet bent by a certain angle returns to a certain angle when the force is stopped. After springback the angle is the main parameter that needs to be monitored during bending.

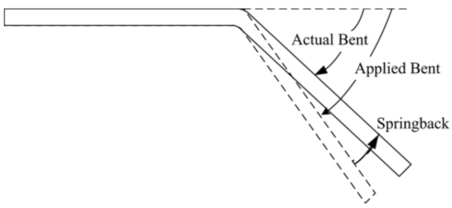

Fig. 2. Springback in sheet-metals bending [7]

III. 3D CAD SHEET METAL PARTS MODELING

Advances in technology and science have led to a sudden increase in the complexity of products and engineering systems, so to develop complex products two different methods can be used: bottom-up and top-down. Bottom-up approach is the more common approach where individual parts are first created and then assembled and positioned. A top-down approach is an approach where parts are developed within an assembly, so positioning and sizing are linked directly to other components within the assembly.

A. Project and description of equipment

Fig. 3 shows the summer kitchen and bar design. Legend of equipment with description is shown in Table I.

TABLE I
DESCRIPTION OF EQUIPMENT

No.	Description	Notes
1	Bar area	
1.1	Bar with preparation for decorative mask (bar wall) and bar top	Dim. 2840x700x900/1120 mm It consists of (right-left): • space for dishwasher • space for sink dim. 340x340x200 mm, faucet diameter d = 33 mm • space for refrigerated counter Material: AISI 304 stainless steel, thickness 1.0 mm
1.2	Professional dishwasher	Dim. 600x603x825 mm
1.3	Water softener	Dim. 240x435x522 mm
1.4	Refrigerated counter with 2 doors	Dim. 1480x699x810 mm Height regulation ± 15 mm
1.5	Back counter	Dim. 1780x600x900 mm It consists of (right-left): • space for garbage bin (dim. Ø390x650 mm) • space for drawer cabinet with 3 drawers • space with bottom shelf closed with double door Countertop with backsplash h = 100 mm Material: AISI 304 stainless steel, thickness 1.0 mm
1.6	Coffee machine	
1.7	Coffee grinder	
1.8	Back counter element	Dim. 920x600x900 mm Work table with bottom shelf closed with double door Countertop with backsplash and right side splash h = 100 mm Material: AISI 304 stainless steel, thickness 1.0 mm
2	Refrigerated display for bottles	Dim. 800x600x525 mm Casing of the refrigerated display for bottles Preparation for insulation, motor, evaporator No preparation for fan Material: AISI 304 stainless steel, thickness 1.0 mm
3	Kitchen	
3.1	Stove	
3.2	Hood	
3.3	Preparation table	Dim. 780/480x730/430x875 mm Space for sink dim. 340x340x200 mm, faucet diameter d = 33 mm Countertop with backsplash and left side splash h = 100 mm Material: AISI 304 stainless steel, thickness 1.0 mm

The material used to manufacture the equipment is austenitic stainless steel X5CrNi18-10, also known as AISI 304. Its key features are high corrosion resistance, resistance, good machinability and excellent weldability. It can be welded with and without filler materials. It is mainly used in food and beverage industry, as well as pharmaceutical and medical industry, architecture, etc.

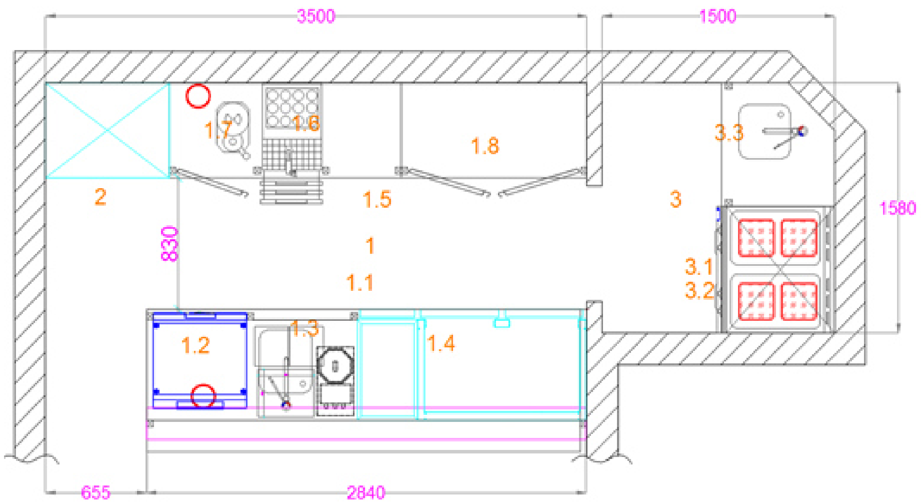

Fig. 3. Summer kitchen and bar design

B. *Sheet Metal Design modeling*

The modeling principle of all equipment parts is very similar. First step is creating a 2D sketch and adding a third dimension – thickness. After the sheet metal base is made, it is necessary to add bends – flanges or hems. Hems are used to eliminate sharp edges and/or to stiffen the sheet metal. The bending radii are given by the bending table shown in Table II. It contains the bending values at different radius values and sheet thicknesses.

TABLE II
BEND TABLE

Unit:	Millimeter								
Type:	Bend Deduction								
Material:	Steel								
Comment:	Values specified are for 90-degree bends								
Radius	**Thickness**								
	0.6	0.8	1.0	1.2	1.5	2.0	2.5	3.0	4.0
1.0	1.3	1.6	1.9	2.3					
1.3	1.4	1.7	2	2.3	2.8				
1.6		1.8	2.1	2.4	2.9	3.7			
2.0			2.2	2.5	3	3.8	4.7		
2.6				2.7	3.2	4	4.8	5.7	
3.3					3.4	4.2	5	5.8	7.5
4.0						4.5	5.2	6	7.7
5.0							5.6	6.3	7.9
6.5								6.8	8.4
8.0									8.9
10.0									

After the part is modeled and all the bends are made, holes or rounded corners are added if it is necessary. Last step of 3D sheet metal modeling is creating a flat pattern and saving it in .dxf format for future nesting process. Calculating flat patterns is done using K-factor because it is related to how much material is stretched during bending. Its value range is between 0 and 0.5.

C. *Creating of subassemblies and assemblies*

After a library of parts was made, it is necessary to assemble created parts into composite model – an assembly or subassembly. Creating an assembly or subassembly is determining the mutual relationship of parts and their behaviour, as well as placing them in certain position. Assemblies show the look of the final product, they help to minimize the possibility of errors. Fig. 4-7 show assemblies of equipment defined in Table I.

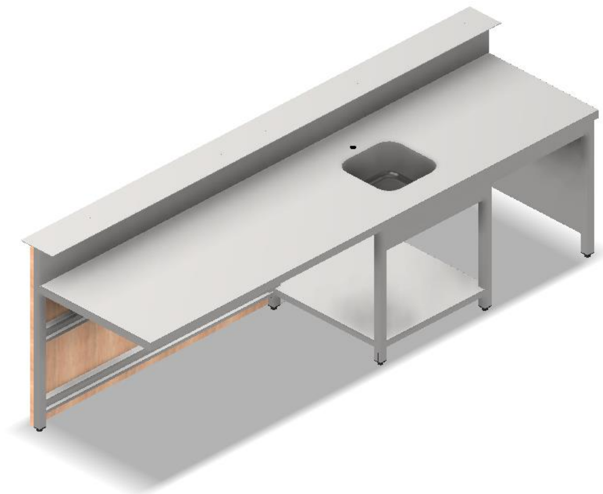

Fig. 4. Bar – equipment 1.1

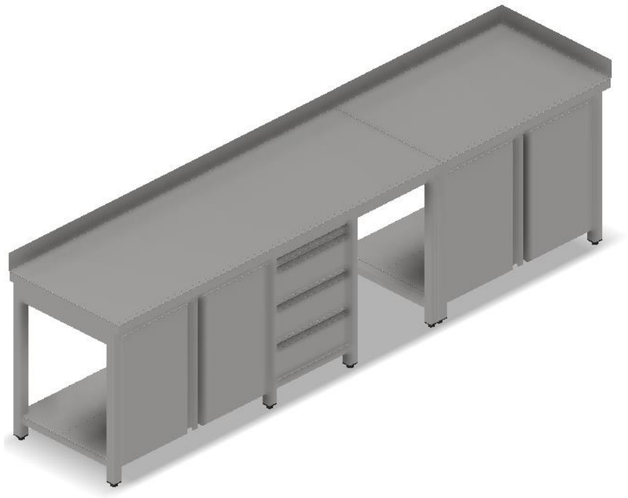

Fig. 5. Back counter – equipment 1.5 and 1.8

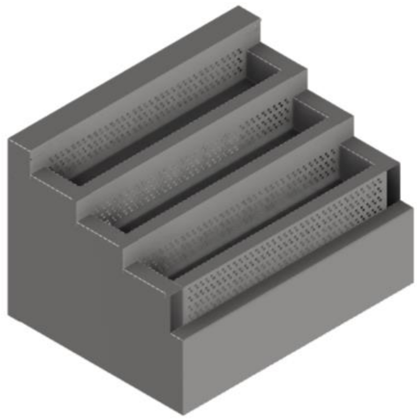

Fig. 6. Casing of the refrigerated display for bottles – equipment 2

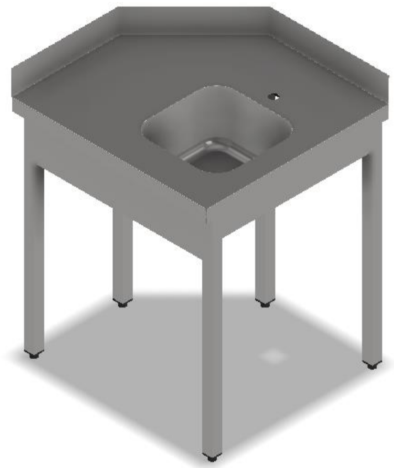

Fig. 7. Preparation table – equipment 3.3

The handles of the doors and drawers are made of one piece as a whole so that they do not tear during use.

IV. PRODUCTION PROCESSES OF FINISHED ASSEMBLIES

A. *Nesting and laser cutting*

Nesting is the process of finding the most efficient arrangement of patterns for cutting in sheet metal manufacturing, in order to reduce material waste (scrap) and cutting time, i.e. production. The main goal is to produce as many parts as possible from as little material as possible.

There are many different nesting software solutions available today. Fig. 8 shows an example created with Deepnest.io software.

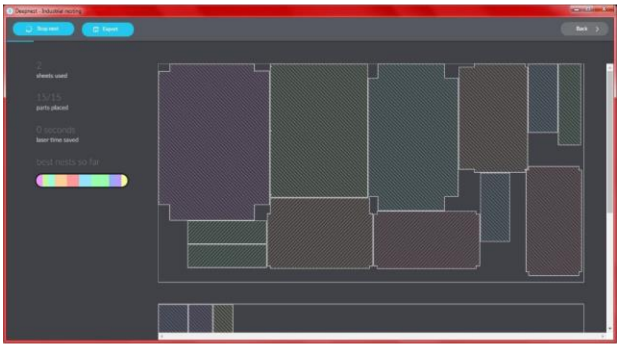

Fig. 8. Nesting process

Cutting in sheet metal manufacturing is most often done by using CO2 laser cutters. The acronym LASER stands for "Light Amplification by Stimulated Emission of Radiation". Laser is actually a generator of monochromatic, coherent and direct light whose main property is the ability to focus on a point with a diameter of < 1 mm. Laser Beam Machining (LBM) is an unconventional advanced manufacturing process in which the material is treated by local melting and evaporation due to the high energy intensity of a focused laser beam. Cutting is done by moving the working head along a certain path.

The CNC system is used to determine the shape and position of the cut lasers. The advantages of using laser cutting compared to mechanical cutting are easier clamping of the workpiece, better cutting precision, no wear of the tool material over time, reduced chance for changes in material structure and mechanical properties due to the creation of a small zone of heat influence, reduction of deformation of the workpiece after cutting etc. One of main disadvantages of laser cutting is high investment [2], [8].

B. *Bending*

After all the positions have been cut, next step is creating a CNC bending program for each part. Fig. 9 shows an example of creating a CNC program using Production Designer software developed by AMADA. The process of generating a code is importing 2D/3D data (part) in the software, the part is then “flattened” and all the features are recognized, finally the software fully automatically generates a complete bending program, including bending sequence and tool selection. Whole process lasts 20-90 seconds. Fig. 10 shows bent part in practice.

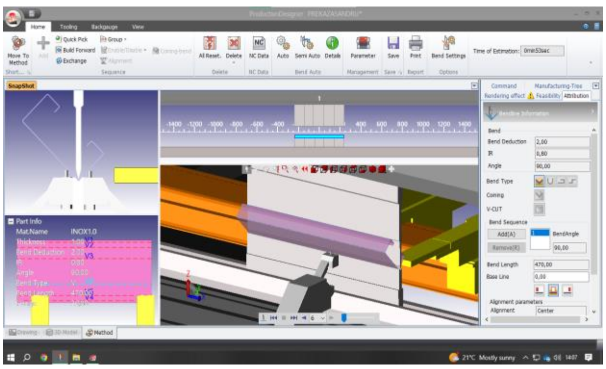

Fig. 9. Generating CNC code for bending

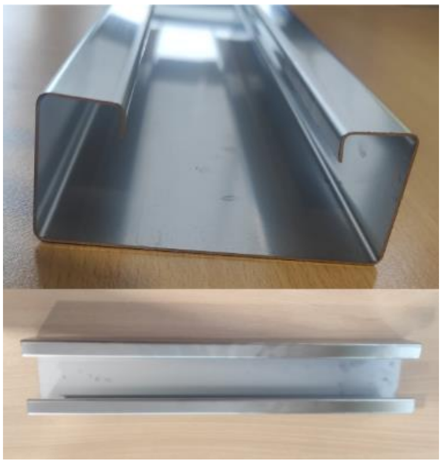

Fig. 10. Bent profile

C. *Assembly and welding*

Assembly of the equipment is done using technical documentation of the parts and assemblies previously created. First step is cutting profiles (tubes) with section dim. 40x40 mm, which represent equipment base, using band saw. Next step is inserting polyvinyl chloride (PVC) insert into catted profiles for height regulation. Parts are mostly joined using TIG (Tungsten Inert Gas) welding process which is also known as WIG (Wolfram Inert Gas) or GTAW (Gas Tungsten Arc Welding). It is most often manual welding procedure that uses a non-consumable W (wolfram, tungsten) electrode and if it is necessary a filler rod. Electrode is protected and cooled by an inert gas, typically argon. TIG welding process features high quality welds due to stable electric arc, good process control without the formation of smoke and slag, it requires high quality preparation of the joint and exceptional skills of the welder. It is suitable for welding thin materials (from 1 - 6 mm). However, it is not economical for welding thicker materials due to the amount of deposited material and low productivity. Welded joints are usually processed by hand using drills with flap rings [9], [10].

V. CONCLUSION

Task of this paper was to make models of commercial kitchen equipment - bar, back counter, casing of the refrigerated display for bottles and preparation table and describe manufacturing process. 3D CAD (Computer Aided Design) software offer relatively simple solution for modeling parts, positioning them into subassemblies and assemblies, as well as creating following technical documentation. Nesting process is preparation for creating a CNC program for laser cutting. Using lasers ensures fast, efficient and accurate processing. CNC programs today are created semi-automatically or automatically using various software solutions for programming. In, assembling parts is mostly done using TIG welding process which provides high quality welds.

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