Researches, studies and development prospects of the quality of metallic parts made on CNC

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Abstract. The quality of products is an important economic indicator. The paper presents studies, researches and development of prospects execution of bent metal parts on CNC machines. Through these studies we tried to find answers regarding the quality of products, problems that many companies face. Laborious studies and research proposed for the paper, on determining the drawings of metal parts (the flat plane). The quality and precision of the products, may influenced by the other variables: the vibrations of machines, tool usage, tolerance between the surface of the bending tools, variation of the temperature during the processes of punching and bending, their usage and the roughness of the metal sheet. The calculations of the drawing pieces must include the bending coefficients Kᵢ. The bending coefficient obtained for steel parts (OL 37) with a thickness of 1 mm, was the subject of the present paper. This coefficient Kᵢ depends on: the type of the material, the chemical composition, the degree of complexity and the number of bends, the movement between the piece and punching or bending tools, vibrations of the machines and other variables. The bending coefficient was obtained by experimental tests and measurements.

1. Introduction

Year 1980 started with a new vision on the global market as the companies worldwide were in an increasingly great globalized competition. In the early 1990s, the world economics system enabled the introduction of ISO 9000 standards. The training of real professionals of quality, had a powerful impact on the commercial relations between countries [1], [11], [12], [13], [14], [15], [16], [17].

The contemporary global market is extremely dynamic. The volume of demand and supply is fluctuating rapidly. The global market in the full era of globalization has no barriers. The same economic products can be found in different markets of the world. Similar needs and preference can be satisfied even if thousands of kilometers separate consumers. Globalization does not consist only of trade relations between countries. It defines an important qualitative and quantitative leap in the entire international economy [2]. The global market of the third millennium offers a new image. It’s a market that belongs to the consumers due to the abundance of the offer.

The contemporary market must offer economical products that can adapt to the client’s needs. In this context, investments should be greater and long-term commitments.

The paper is based on the laborious studies and researches, on determining the drawings of the metal parts type OL37 with 1 mm. The research was initiated on the basis of an important
consideration. The bending is very important in the technological flow of achievement. The quality and conformity of the profiled product depending on this operation.

The main objective of the research was to determine the optimum bending coefficient. The studies and researches have unfolded over a long period of time. Studies and research have been completed, but they can be resumed at any time and improved.

Through the paper answers are offered regarding the quality of the products. Improving product quality is a general problem facing companies. Finally, the quality of economic products reflects path to excellence compared to non-quality.

2. Important technical requirements
The research was performed in two stages respectively in two different companies. In the first company the bending coefficient $K_f$ for metal products with a thickness between one and three mm was determined. The products were made on the following machines with CNC, respectively:
- Hydraulic guillotine model CNC HVR 3100 x 10;
- Stamping machine TC 200R;
- Stamping machine type BOSCHERT;
- Bending machine type G BEND.

In this stage, the bending coefficients resulted after measurements and tests. The results obtained were not conclusive which determined the extension of research and studies, on other machines with CNC.

The second stage of the research and studies introduced a variety of possibilities used to determine the drawings (flat parts) of the components. The machines used to execute metal parts were:
- Stamping machine TRUPUNCH 3000R with CNC;
- Bending Machine ERM 30135.

The drawings of the metal parts were calculated in four ways:
- a) Using the coefficient resulted in the first stage $K_{A1}$;
- b) Mathematical on neutral fiber;
- c) On neutral fiber using the coefficients obtained from the Tables $K_{EL}$;
- d) The coefficient established by the machine software $K_{soft}$.

The bending coefficient was determined by experimental tests and measurements. This bending coefficient depending on the material thickness, chemical composition, its quality and the bending complexity. They are many other variables that can influence the bending operation, respectively:
- The quality of material;
- Chemical and physical-mechanical properties of materials;
- The quality of tools;
- Vibrations of the machines;
- The movement between the surface of the punch and the die;
- Incorrect use of CNC machines;
- The roughness of the sheet metal as a result of lamination process;
- Heating tools during punching operation;
- Improper use or degraded tools for punching and bending operations;
- Other variables can influence the conformity and quality of the metal product created with digital control machines.

The precision and quality of the metal parts were influenced by the presence of the other variables. The machine/tool system was affected by the presence of these variables [3]. They are not included in the software used the computer aided design and execution [11], [12], [13], [14], [15], [16], [17].

The determination of the bending coefficient for the execution of the metallic parts of steel OL37 with a thickness of 1 mm is very important.

The contribution of the study consists in the realization of the metallic products that respect the dimensions and the deviations to size (according to the execution drawings).

2.1. Cutting parts by punching on CNC machines
The optimal bending coefficient was determined by experimental tests and measurements. For this, very important was the calculation of the unfolds (flat parts). They also contain the deformations produced during the bending operation. Steel parts with a thickness of 1 mm were executed using the stamping machines TC 200R and TRUPUNCH 3000R.

Three types of parts, of different complexities, were executed. For each type of drawing, four types of unfolding were calculated.

In the first stage of study and research, the establishment of the bending coefficient was determined on batches of 10 pieces. For each type of piece, 5 lots were made. The bending coefficient $K_{A1}$ was determined by experimental tests and measurements. For parts with a thickness of 1 mm, $K_{A1} = -0.04$ mm / bending at 90 degrees (for sample no.1, 5, 9) [14].

For sample no. 2, 6 and 10, the calculation of the drawings of the parts on neutral fiber was determined according:

- The thickness of the material;
- The bending angle;
- The bending radius.

The drawings for sample no. 3, 7, 11 were calculated on coefficient $K_{E3} = -1.8$ mm / bending at 90 degrees angle. The coefficient $K_{E3}$ was chosen depending on the thickness of the material and the radius of the bending punch $R = 0.25$ mm.

The drawings for sample no. 4, 8, 12 were calculated by the bending machine software, using a coefficient $K_{soft}$.

In Figure 1 was represented the type piece “L support” for sample no. 1, 2, 3 and 4 (Figure 1).

![Figure 1. L Support (Sample: no. 1, no. 2, no. 3, no. 4)](image)

The drawing of sample no. 3 image 10 - 3 - L (Figure 2) was calculated using the bending coefficient $K_{E3} = -1.8$ mm / bending at 90 degrees angle. To the right of the drawing, was indicated the bending dimension of the piece. For samples no. 1, 2, 4, the widths of the drawings are according to Table 1.

![Figure 2. The drawing of sample no. 3 (L Support)](image)

For the sample no. 5, 6, 7 and 8 (Figure 3) was represented the type piece “U Support”.

![Figure 3. The drawing of sample no. 5, 6, 7 and 8 (U Support)](image)
The drawing of sample no. 7 image 10 - 3 - U (Figure 4) was calculated using the bending coefficient $K_{E3} = -1.8 \text{ mm} / \text{bending at 90 degrees angle}$. To the right of the drawing, were indicated the bending dimensions of the part. The widths of the other samples 5, 6 and 8 are according to Table 1.

The profile of “Omega Support” was indicated in the Figure 5. It is valid for samples no. 9, 10, 11 and 12.
The drawing of the sample no. 11 image 10 - 3 - omega (Figure 6) was calculated with the bending coefficient \( K_{E3} = -1.8 \text{ mm / bending at 90 degrees angle} \). The bending dimensions of the parts were indicated to the right of the drawing. The widths of the samples 9, 10, 12 are according to Table 1.

**Figure 6.** The drawing of the sample no. 11 (Omega Support)

| Sample name       | Determined by tests and measurements \( K_{Ai} \) | Calculated on neutral fiber | Calculated on neutral fiber with coefficient \( K_{E3} \) | Calculated by the bending machine software \( K_{soft} \) |
|-------------------|---------------------------------|---------------------------|---------------------------------|---------------------------------|
| L Support Sample no. 1 ÷ 4 | 35.46                          | 35.77                     | 35.7                            | 35.78                           |
| U Support Sample no. 5 ÷ 8  | 85.92                          | 86.55                     | 86.4                            | 86.46                           |
| Omega Support Sample no. 9 ÷ 12 | 109.3                          | 110.61                    | 110.42                          | 112.92                          |

The unfolds of the pieces executed on the MUCN, in the four proposed variants, were centralized in Table 1.
2.2. The results of the measurements after the punching operation on the machine TRUPUNCH 3000R

Measurements of the dimensions were made after the punching operation, according to the calculated drawings and the execution on the CNC machines. There was a difference between the drawings of samples. That increase gradually, depending on the complexity and the number of the bent component [6].

The samples debited by the stamping machine TRUPUNCH 3000R or TC 200R, were measured using the digital caliper Mitutoyo. That has a precision of ± 0.01 mm. The stamping precision according to the specifications of the machine TRUPUNCH 3000R is ± 0.01 mm. From every type of sample, five pieces was executed (Table 2).

### Table 2. Measuring the dimensions of the samples after the punching (mm)

| Sample no. | No. drawing | Calculated unfolding of the piece | Sample no. 1 | Sample no. 2 | Sample no. 3 | Sample no. 4 | Sample no. 5 |
|------------|-------------|----------------------------------|--------------|--------------|--------------|--------------|--------------|
| Sample no. 1 | 10 - 1 - L   | 35.46                            | 35.47        | 35.45        | 35.47        | 35.47        | 35.47        |
| Sample no. 2 | 10 - 2 - L   | 35.77                            | 35.77        | 35.78        | 35.77        | 35.79        | 35.79        |
| Sample no. 3 | 10 - 3 - L   | 35.7                             | 35.74        | 35.72        | 35.72        | 35.71        | 35.71        |
| Sample no. 4 | 10 - 4 - L   | 35.78                            | 35.8         | 35.79        | 35.79        | 35.79        | 35.79        |
| Sample no. 5 | 10 - 1 - U   | 85.92                            | 85.92        | 85.92        | 85.94        | 85.92        | 85.93        |
| Sample no. 6 | 10 - 2 - U   | 86.55                            | 86.55        | 86.55        | 86.55        | 86.56        | 86.56        |
| Sample no. 7 | 10 - 3 - U   | 86.4                             | 86.41        | 86.4         | 86.41        | 86.41        | 86.41        |
| Sample no. 8 | 10 - 4 - U   | 86.46                            | 86.46        | 86.46        | 86.46        | 86.46        | 86.46        |
| Sample no. 9 | 10 - 1 - Omega | 109.3                          | 109.34       | 109.33       | 109.35       | 109.33       | 109.35       |
| Sample no. 10 | 10 - 2 - Omega | 110.61                         | 110.6        | 110.6        | 110.6        | 110.6        | 110.61       |
| Sample no. 11 | 10 - 3 - Omega | 110.42                         | 110.42       | 110.42       | 110.42       | 110.42       | 110.41       |
| Sample no. 12 | 10 - 4 - Omega | 112.92                         | 112.94       | 112.93       | 112.93       | 112.94       | 112.93       |

For the samples from the OL 37 sheet with the thickness 1 mm, the deviations allowed at the nominal dimensions were indicated in Table 3.

### Table 3. Deviations allowed at nominal dimensions of the samples (mm)

| Sample no. | The unfolding of the pieces | Deviations from the nominal dimensions | Sample no. / The unfolding of the pieces | Deviations from the nominal dimensions |
|------------|-----------------------------|----------------------------------------|-----------------------------------------|----------------------------------------|
| Sample no. 1 | 35.46                       | 35.36 ± 35.56                           | Sample no. 2                            | 35.77                                  | 35.67 ± 35.87                           |
| Sample no. 3 | 32.7                        | 32.6 ± 32.8                             | Sample no. 4                            | 35.78                                  | 35.68 ± 35.88                           |
| Sample no. 5 | 85.92                       | 85.82 ± 86.02                           | Sample no. 6                            | 86.55                                  | 86.45 ± 86.65                           |
| Sample no. 7 | 86.4                        | 86.3 ± 86.5                             | Sample no. 8                            | 86.46                                  | 86.36 ± 86.56                           |
| Sample no. 9 | 109.3                       | 109.2 ± 109.4                           | Sample no. 10                           | 110.61                                 | 110.51 ± 110.71                         |
| Sample no. 11 | 110.42                      | 110.32 ± 110.52                         | Sample no. 12                           | 112.92                                 | 112.82 ± 113.02                         |
After the punching operations, the dimensions of the parts were within the allowed limits. Important were the deviations of the parts, after the bending operations. Finally, the deviations in size, summed up the deviations that appeared after the punching and bending operations.

2.3. Bending semi-manufactures materials

The executions of the bent parts were made in an important center equipped with machines with numerical control. The production of metal parts in accordance with the execution drawings, depended on the experience and professionalism of the workers.

Bending occurs under the action of an external force of tangential descent on the punch to the surface of the part (Figure 7). A plastic deformation of the material occurs due to exceeding the elastic limit [8], [12], [13], [14], [15], [16], [17].

During the bending of the workpiece products:
- Tensile forces appear on the outside (the outer fibers lengthen);
- Compressive forces on the inside (the inner fibers shorten).

Between the two areas subject to deformation, the neutral layer area appears, where the efforts are zero [18].

The unfolds were calculated according to the thickness of the material, the chemical composition and the tools used for bending [9].

For bending OL 37 parts with a thickness of 1 mm were selected:
- A punch with \( R = 0.25 \) mm type 1270 - R0.25 – 88\(^{0}\) – H 94.35;
- A die with an opening \( V = 6 \) mm, type 3073 – V6 – 30\(^{0}\) – H 120.

A tool adjustment was made before starting the bending operations for the samples no. 1 ÷ 12 (Figure 9).
For bending the pieces type “L Support” the data was entered in the control panel of the CNC machine. Parameters necessary for the execution of bending operations were:

- The thickness of the material (g = 1 mm);
- The type of punch and die used during bending operations;
- The distance of the part to the limiters;
- The speed of lowering the punch.

For samples no. 1, 2, 3, 4 the bending operation and the necessary tools were indicated in Figure 10.

Bending operations for samples 5, 6, 7, 8 were indicated in Figure 11.
In Figure 12 were presented the bending operations for making the parts no. 9, 10, 11 and 12 (Omega Support).

![Figure 12. Bending operations for samples no. 9, 10, 11 and 12 (Omega Support)](image)

2.4. The results of the measurements after the bending operation on the CNC machine

The maximum deviations from the nominal dimensions were presented in the Table 4. After measuring the samples, the data were centralized in Table 5.

| Tolerance class | From: 0.5 mm up to 3 mm | From: 3 mm up to 6 mm | From: 6 mm up to 30 mm | From: 30 mm up to 120 mm |
|-----------------|------------------------|-----------------------|------------------------|-------------------------|
| Fine            | ±0.05                  | ±0.05                 | ±0.1                   | ±0.15                   |
| Middle          | ±0.1                   | ±0.1                  | ±0.2                   | ±0.3                    |
| Rough           | ±0.2                   | ±0.3                  | ±0.5                   | ±0.8                    |
| Gross           | -                      | ±0.5                  | ±1                     | ±1.5                    |
After the bending operations of the “L Support” samples, they were measured. The data were centralized in Table 5.

Table 5. The results of the measurements after the bending operations (mm)

| L Support | Piece no. 1 | Piece no. 2 | Piece no. 3 | Piece no. 4 | Piece no. 5 |
|-----------|-------------|-------------|-------------|-------------|-------------|
| The nominal dimensions | 12.5 mm | 25 mm | 12.5 mm | 25 mm | 12.5 mm | 25 mm | 12.5 mm | 25 mm | 12.5 mm | 25 mm |
| Sample no. 1 | 12.46 | 24.67 | 12.48 | 24.69 | 12.68 | 24.48 | 12.57 | 24.61 | 12.49 | 24.67 |
| Allowed deviations | -0.04 | -0.33 | -0.02 | -0.31 | 0.18 | -0.02 | +0.07 | -0.39 | -0.01 | -0.33 |
| Sample no. 2 | 12.47 | 25 | 12.49 | 24.98 | 12.45 | 24.97 | 12.49 | 24.97 | 12.5 | 24.97 |
| Allowed deviations | -0.03 | 0 | -0.01 | -0.02 | -0.05 | -0.03 | -0.01 | -0.03 | 0 | -0.03 |
| Sample no. 3 | 12.45 | 24.92 | 12.5 | 24.89 | 12.49 | 24.89 | 12.48 | 24.91 | 12.49 | 24.92 |
| Allowed deviations | -0.05 | -0.08 | 0 | -0.11 | -0.01 | -0.11 | -0.02 | -0.09 | -0.01 | -0.08 |
| Sample no. 4 | 12.5 | 25 | 12.5 | 25 | 12.49 | 25.02 | 12.49 | 25.02 | 12.49 | 25.01 |
| Allowed deviations | 0 | 0 | 0 | 0 | -0.01 | +0.02 | -0.01 | 0.02 | -0.01 | +0.01 |

“U Support” parts were measured after bending operations. The data were centralized in Table 6.

Table 6. The results of the measurements after the bending operations (mm)

| U Support | Piece no. 1 | Piece no. 2 | Piece no. 3 | Piece no. 4 | Piece no. 5 |
|-----------|-------------|-------------|-------------|-------------|-------------|
| The nominal dimensions | 25 | 40 | 25 | 40 | 25 | 40 | 25 | 40 | 25 | 40 |
| Sample no. 5 | 24.84 | 39.54 | 24.91 | 24.86 | 39.56 | 24.89 | 24.86 | 39.55 | 24.89 | 39.5 | 24.86 | 39.68 | 24.88 |
| Allowed deviations | -0.16 | -0.46 | -0.09 | -0.14 | -0.44 | -0.11 | -0.14 | -0.45 | -0.11 | -0.09 | -0.5 | -0.09 | -0.14 | -0.32 | -0.12 |
| Sample no. 6 | 25.05 | 39.83 | 25.05 | 25.03 | 39.9 | 24.98 | 25.04 | 39.87 | 25.02 | 24.97 | 38.89 | 25.09 | 25.05 | 39.9 | 25.03 |
| Allowed deviations | 0.05 | -0.17 | 0.05 | 0.03 | -0.1 | -0.02 | 0.04 | -0.13 | 0.02 | -0.03 | -1.11 | 0.09 | 0.05 | -0.1 | 0.03 |
| Sample no. 7 | 24.97 | 39.87 | 24.97 | 24.85 | 40.09 | 24.89 | 24.99 | 38.89 | 25.04 | - | - | - | - | - | - |
| Allowed deviations | -0.03 | -0.13 | -0.03 | -0.15 | 0.09 | -0.11 | -0.01 | -1.11 | 0.04 | - | - | - | - | - | - |
| Sample no. 8 | 24.97 | 39.97 | 24.94 | 24.93 | 39.94 | 24.97 | 24.98 | 39.94 | 24.95 | 24.78 | 40.08 | 24.97 | 24.97 | 39.92 | 24.96 |
| Allowed deviations | -0.03 | -0.03 | -0.06 | -0.07 | -0.06 | -0.03 | -0.02 | -0.06 | -0.05 | -0.22 | 0.08 | -0.03 | -0.03 | -0.08 | -0.04 |

The dimensions obtained after bending for “Omega Support” were centralized in the Table 7.
Deviations from nominal dimensions gradually increase, depending on the complexity of the piece, the thickness of the material, the number of bends and the quality on tools used [10].

| Omega Support | Sample no. 9 | Allowed deviations (mm) | Sample no. 10 | Allowed deviations (mm) | Sample no. 11 | Allowed deviations (mm) | Sample no. 12 | Allowed deviations (mm) |
|---------------|--------------|-------------------------|---------------|-------------------------|---------------|-------------------------|---------------|-------------------------|
| Piece no. 1   | 10           | 9.99                    | -0.01         | 9.82                    | -0.18         | 9.73                    | -0.27         | 9.83                    | -0.17                   |
|               | 20           | 19.98                   | -0.02         | 19.89                   | -0.11         | 20.02                   | +0.02         | 19.89                   | -0.11                   |
|               | 55           | 54.16                   | -0.84         | 55.48                   | +0.48         | 55.25                   | +0.25         | 57.66                   | +2.66                   |
|               | 20           | 19.84                   | -0.16         | 19.7                    | -0.3          | 19.94                   | -0.06         | 19.92                   | -0.08                   |
|               | 12.5         | 12.38                   | -0.12         | 12.46                   | -0.04         | 12.43                   | -0.07         | 12.42                   | -0.08                   |
| Piece no. 2   | 10           | 9.79                    | -0.21         | 9.91                    | -0.09         | 9.88                    | -0.12         | 9.88                    | -0.12                   |
|               | 20           | 20.13                   | +0.13         | 19.86                   | -0.14         | 19.87                   | -0.13         | 19.93                   | -0.07                   |
|               | 55           | 53.98                   | -1.02         | 55.51                   | +0.51         | 55.18                   | +0.18         | 57.62                   | +2.62                   |
|               | 20           | 20.00                   | 0             | 19.97                   | -0.03         | 19.83                   | -0.17         | 19.89                   | +0.11                   |
|               | 12.5         | 12.43                   | -0.07         | 12.43                   | -0.07         | 12.45                   | -0.05         | 12.45                   | -0.05                   |
| Piece no. 3   | 10           | 9.88                    | -0.12         | 9.86                    | -0.14         | 9.91                    | -0.09         | 9.81                    | -0.19                   |
|               | 20           | 19.94                   | -0.06         | 19.96                   | -0.04         | 19.96                   | -0.04         | 19.95                   | -0.05                   |
|               | 55           | 53.98                   | -1.02         | 55.34                   | +0.34         | 55.08                   | +0.08         | 57.66                   | +2.66                   |
|               | 20           | 19.9                    | -0.1          | 19.81                   | -0.19         | 19.86                   | -0.14         | 19.97                   | -0.03                   |
|               | 12.5         | 12.38                   | -0.12         | 12.46                   | -0.04         | 12.41                   | -0.09         | 12.48                   | -0.02                   |
| Piece no. 4   | 10           | 9.92                    | -0.08         | 9.83                    | -0.17         | 9.8                     | -0.2          | 9.76                    | -0.24                   |
|               | 20           | 19.91                   | -0.09         | 19.89                   | -0.11         | 19.94                   | -0.06         | 19.99                   | -0.01                   |
|               | 55           | 53.99                   | -1.01         | 55.43                   | +0.43         | 55.22                   | +0.22         | 57.7                    | +2.7                    |
|               | 20           | 19.9                    | -0.1          | 19.84                   | -0.16         | 19.92                   | -0.08         | 19.92                   | -0.08                   |
|               | 12.5         | 12.45                   | -0.05         | 12.49                   | -0.01         | 12.4                    | -0.1          | 12.41                   | -0.09                   |
| Piece no. 5   | 10           | 9.91                    | -0.09         | 9.90                    | -0.1          | 9.83                    | -0.17         | 9.8                     | -0.2                    |
|               | 20           | 19.88                   | -0.12         | 19.85                   | -0.15         | 19.94                   | -0.06         | 19.92                   | -0.08                   |
|               | 55           | 54.08                   | -0.92         | 55.25                   | +0.25         | 55.15                   | +0.15         | 57.62                   | +2.62                   |
|               | 20           | 19.82                   | -0.18         | 19.89                   | -0.11         | 19.93                   | -0.07         | 19.96                   | -0.04                   |
|               | 12.5         | 12.44                   | -0.06         | 12.49                   | -0.01         | 12.46                   | -0.04         | 12.46                   | -0.04                   |

3. Conclusions
1. From the analysis and comparison of the results it was concluded that the deviations of the samples were within the allowed limits (of the deviations in dimensions).
2. The deviations from the nominal dimensions was caused by the vibrations that occur during the stamping process but and the bending operations.
3. The existence of factors that produce vibrations during the stamping, for example:
   - The high speed in changing the tools, the movement of the tools on high routes (metal sheet has the surface 1500 x 3000 mm²);
   - The forces created during the stamping process that can reach up 20 KN;
Using improper tools during stamping can produce high vibrations, even if the machine has a solid structure.

4. The punching machine TRUPUNCH 3000R is extremely efficient and very productive, the transfer speed on axis Ox is 90 m/min and on axis Oy is 60 m/min. The vibrations that occur during the punching process are inevitable.

5. The surface of the metal sheets due to lamination, as this has an uneven thickness has a negative influence.

6. During the punching and bending operations of the parts, their quality is adversely influenced by certain factors, respectively:
   - Use of improper tools (affected by wear, uncalibrated or made of improper materials);
   - Heating of tools during the execution of parts due to improper work regimes;
   - CNC machine vibrations due to high punching speeds, improper adjustments or the choice of higher bending forces.
   - Choosing materials with inadequate hardness;
   - High roughness of materials used;
   - The use of steel sheets that have burns and cracks;
   - Large variations in ambient temperature.

7. The bending coefficients $K_i$ must compensate for deviations from the nominal dimensions due to the multiple variables that negatively influence the quality of the parts.

8. The dimensions of the parts made by punching were in the fine precision class.

9. After the bending operations most of the parts were executed in the fine and middle execution class.

10. For OL 37 sheet metal parts with a thickness of 1 mm, the bending coefficient established following studies and researches was $K_i = 0.28 \text{ mm} / \text{bending at 90 degrees angle}$. The set bending coefficient is valid only for bends at 90 degrees.

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