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# CHARACTERISTIC OF SHAPING TITANIUM SHEETS BY COLD WORKING METHODS

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In the paper, some problems occurring during sheet-metal forming of titanium alloys have been discussed. Attention has been paid to the role of lubrication. The test results of frictional coefficient for some technological lubricants and antiadhesive layers have been given.

**Key words:** sheet-metal forming, titanium sheet, friction, lubrication.

## 1. Introduction

High competition in the production of high quality goods at low production costs becomes a symbol of our days. It also applies to sheet-metal working, which represents an essential part of the modern industry. Sheet-metal forming processes are applied in many industries such as: car industry (car-bodies, parts of chassis), electrochemical industry (different kind of housings) or domestic appliances (tubs, sinks, pots etc.). The leading role plays the car industry, which is still strictly connected with the development of the modern steel industry. Every year a range of materials used in sheet-metal forming processes becomes wider. Apart from typical car body sheets, the sheets such as: aluminium, stainless steel, titanium or magnesium alloys are shaped more and more often. It entails a necessity of solving new technological problems. The main aim of the application of light alloys is a decrease in construction weight to generate measurable economic and ecological effects.

The application of titanium and its alloys in technology and medicine becomes more and more popular. Its exceptional advantages such as:

- low specific gravity $4.43 \div 4.85\, g/cm^3$ ,
- high mechanical properties (tensile strength from $R_m \approx 240\, MPa$ for commercially pure – CP titanium grade *1* to $R_m \approx 1750\, MPa$ for heat treated beta alloys (Boyer ***et al.***, 1994),
- good corrosion resistance experienced in many environments thanks to the thin but stable oxide protective layer (mainly $TiO_2$)

are recognized more and more often. A growth of the thickness of the oxide layer, which normally forms in nature, can be accelerated in higher temperature or in anodizing process.

A combination of high strength and low density causes titanium alloys to outstrip those of other metals. Thanks to the highest strength to weight ratio titanium is used everywhere the construction weight and strength is of importance such as aircraft, sporting equipment (bicycles, skis, rackets, wheelchairs etc.) and medicine (surgical implants, surgical instrumentarium). Moreover, titanium alloys exhibit modulus of elasticity values which are approximately *50%* of steel so they are the right material for springs and human prosthetic devices. Unfortunately, application of the newest high strength titanium alloys in the civilian sector is still limited. Medicine is one of the most important areas of our life where titanium and its alloys are applied. In this case biocompability is an especially essential factor deciding of their application. Stamping is

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applied to produce some elements of the knee endoprostheses such as: clamping plates of the polyethylene inserts, condyle elements of the sled endoprostheses etc. Different casings, e.g. casings of the artificial heart chamber, casings of the endoprostheses acetabular cups are produced by stamping technology too. Moreover, stamping is also applied to produce some tool elements used for endoprostheses implantation e.g. cutterhead for drilling holes on the acetabular cups etc. Figure 1 presents some examples of the products making by stamping technology for medicine.

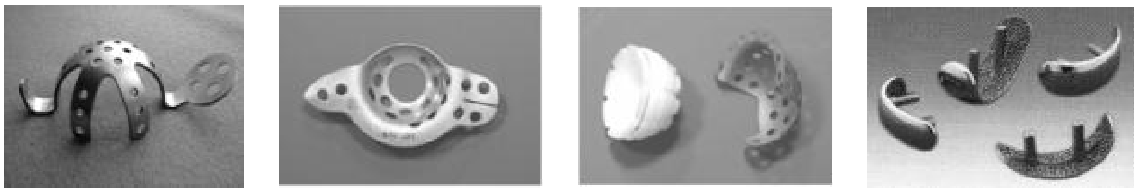


Fig.1. Examples of titanium products made by stamping technology (prospects, Wójcik *et al.*, 2003).

## 2. Titanium as a material used for the drawn-parts

Titanium sheets can be shaped by cutting, bending, stamping, spinning and hydraulic bulging. The sheets applying for the drawn-parts should have the proper plastic properties (annealed state) and microstructure.

CP titanium grade *1* has the best drawability. The harder CP titanium grades require greater corner radius and higher forces for shaping. Additionally, forming speed should be kept as low as possible, thus good results are obtained on hydraulic presses. Sometimes, during cold stamping processes, it is necessary to apply intermediate annealing. In order to remove internal stresses the final products must undergo stress relief annealing. Both intermediate and stress relief annealing should be carried out with the protective atmosphere.

Generally, titanium alloys are marked by poor drawability, which can be improved by hot forming. Usually, both titanium blanks and dies are warmed up. As a result lower spring-back occurs and consequently it is possible to obtain better dimensional accuracy of the drawn-parts. Unfortunately, elevated temperature processing must be used under special conditions (vacuum or protective atmosphere) in order to avoid gas diffusion into titanium because of its reactive nature. Titanium's susceptibility to oxygen, nitrogen, and hydrogen causes titanium to become more brittle (Melechov *et al.*, 2004).

The galling tendency of titanium is another important problem during stamping (Gierzyńska-Dolna, 1992; Mori *et al.*, 2003). Galling marks the surface of the titanium drawn-parts causing local scratches and dents. The „build-ups" phenomenon can be limited or even completely eliminated by the application of technological lubricants and antiadhesive coatings on the tools.

Furthermore, the titanium price hinders rather than helps in common application of titanium alloys. Both manufacturing costs and the fact that titanium has been treated as a strategic material for many years caused that there are only few publications in the field of titanium forming, especially by sheet-metal forming methods.

## 3. Aim and range of the tests

The tests were aimed at determining mechanical properties and the friction coefficient of some titanium sheets.

The following titanium sheets:

- commercially pure titanium grade *2* with the thickness $g = 1.0\,mm$,
- Ti6Al4V with the thickness $g = 1.0\,mm$,

whose chemical constitution is given in Tab.1, have been tested.

Table 1. Chemical constitution of the tested sheets (Boyer *et al.*, 1990).

| material: CP titanium grade *2* | | | | | | |
|---|---|---|---|---|---|---|
| component | C | Fe | H | N | O | Ti |
| wt% | max.*0,1* | max.*0,3* | max.*0,015* | max.*0,03* | max.*0,25* | *99,2* |
| material: Ti6Al4V | | | | | | |
| component | Al | Fe | O | Ti | V | |
| wt% | *6* | max.*0,25* | max.*0,20* | *90* | *4* | |

Mechanical properties: tensile strength $R_m$, yield point $R_e$ and alongation $A$ were determined on the basis of the tensile test. The tests were carried out on the INSTRON 4483 Tester at the Metal Forming Institute - Poznań. Samples cut out from the titanium sheet at the angle of $0^0$, $45^0$ and $90^0$ to the rolling direction were tested.

Friction coefficient was determined on the basis of the "strip-drawing" test (Adamus, 1998), as it is shown in Fig.2. Titanium strips were drawn between two flat jaws. The jaws were made of NC6 tool steel with a different surfacing: grinding and polishing, chromium plating and nitriding. Tests were carried out with some lubricants and in a dry condition.

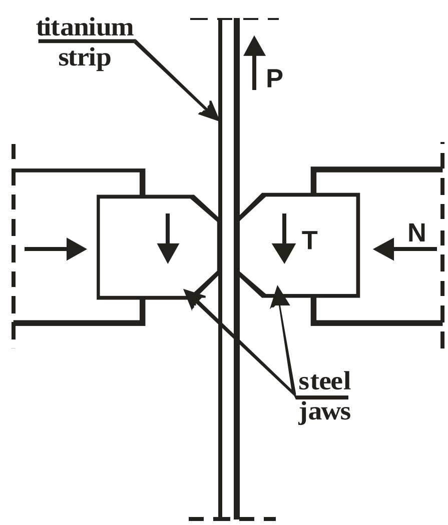



Fig.2. Scheme of the "strip-drawing" test.

## 4. Test results

Drawability of titanium sheets can be assessed, among other things, on the basis of mechanical properties i.e., $R_e$ i $R_m$. The tests results are presented in Tab.2 and Fig.3.

Table 2. Mechanical properties for the tested sheet.

| No | material | direction of the sample to the rolling direction | $R_e[MPa]$ | $R_m[MPa]$ | $R_e/R_m$ ratio | Strain-hardening coefficient $n$ |
|---|---|---|---|---|---|---|
| 1. | CP2 | *0⁰* | *368* | *522* | *0,70* | *0,13* |
| 2. | | *45⁰* | *399* | *486* | *0,82* | *0,10* |
| 3. | | *90⁰* | *424* | *496* | *0,85* | *0,08* |
| 4. | Ti6Al4V | *0⁰* | *999* | *1048* | *0,95* | *0,04* |
| 5. | | *45⁰* | *994* | *999* | *0,99* | *0,01* |
| 6. | | *90⁰* | *1035* | *1049* | *0,99* | *0,02* |

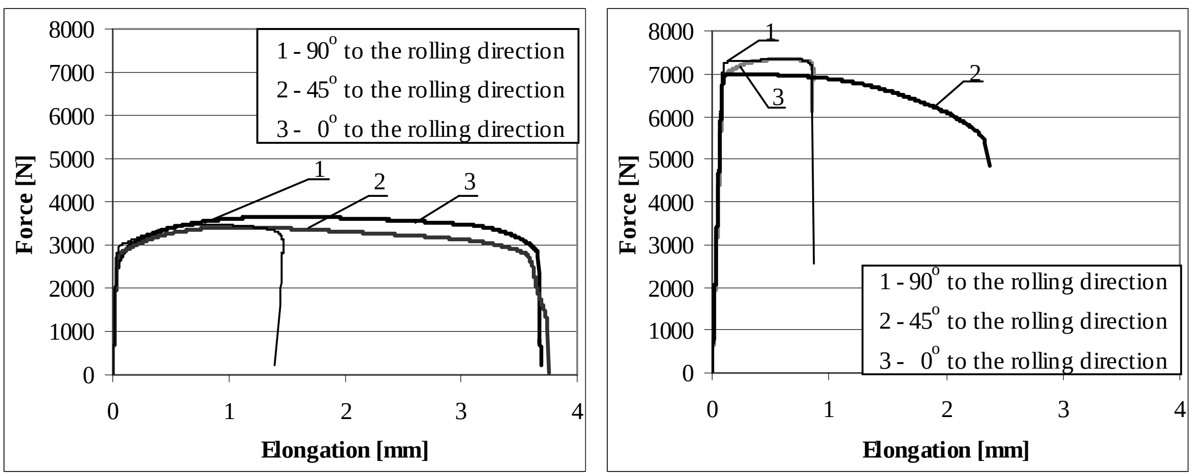



Fig.3. Results of the tensile test a) CP titanium grade *2*, b) Ti6Al4V.

The sheet-titanium forming process, especially of Ti6Al4V alloy, is much more difficult than the sheet-steel forming process. The difficulty results from both the high yield point and tensile strength and the high value of the $R_e/R_m$ ratio.

Moreover, titanium sheets show high frictional resistance and susceptibility to the creation of titanium build-ups on the tool surface. In order to test the lubricant influence on the frictional coefficient the “strip-drawing” test was carried out. The test results of the friction coefficient are presented in Figs 4-6.

According to the laboratory tests technological lubricants affect the friction coefficient significantly. It results in lowering of the tool wear. The best results were obtained for the lubricant with $MoS_2$ additive. The Oil lubricant No P also has a low friction coefficient but due to high viscosity there were difficulties in spraying and removing it from the surface.

Additionally, lubrication limits direct contact between the deformed material and the tool, so eliminates the possibility of “build-ups” creation on the tool – the main reason of adhesive wear. Figure 4, for example, shows changes in surface roughness in a “strip-drawing” test carried out for the tools with and without surfacing.

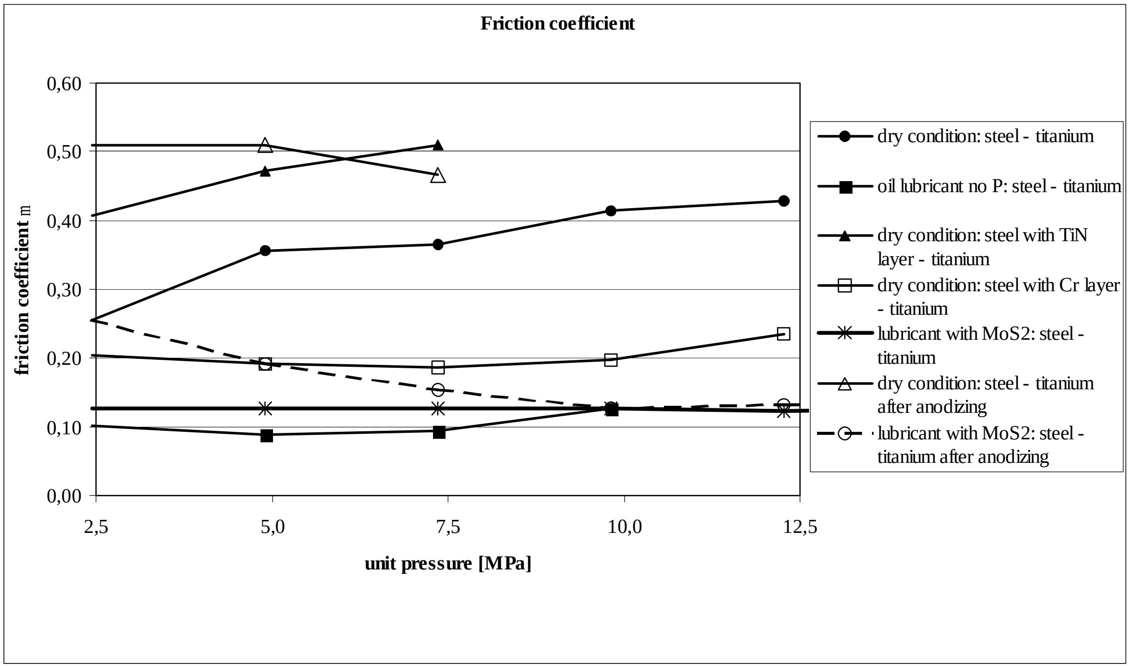
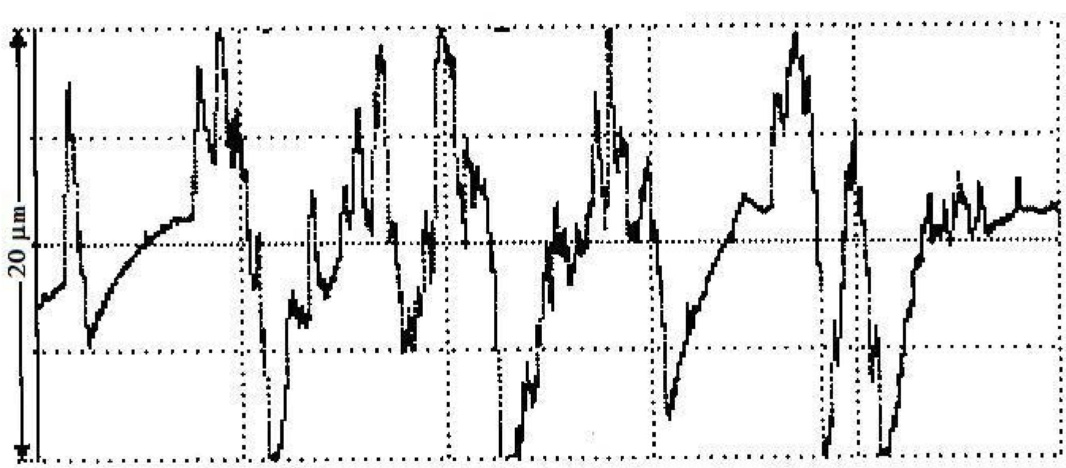



Fig.4. Test results of the friction coefficient. Frictional pair: „tool steel – titanium sheet".

In dry condition, tests were carried out for the tool inserts both with TiN and Cr layers and without any layer. The results are presented in Fig.3.

According to Fig.5 an effective decrease in the friction coefficient was obtained for the tool inserts with a chromium layer. TiN layer seems not to be effective for titanium sheets shaping. Anodizing the titanium sheet also did not reduce the friction coefficient what was suggested in Mori *et al*., 2003.

a)



b)

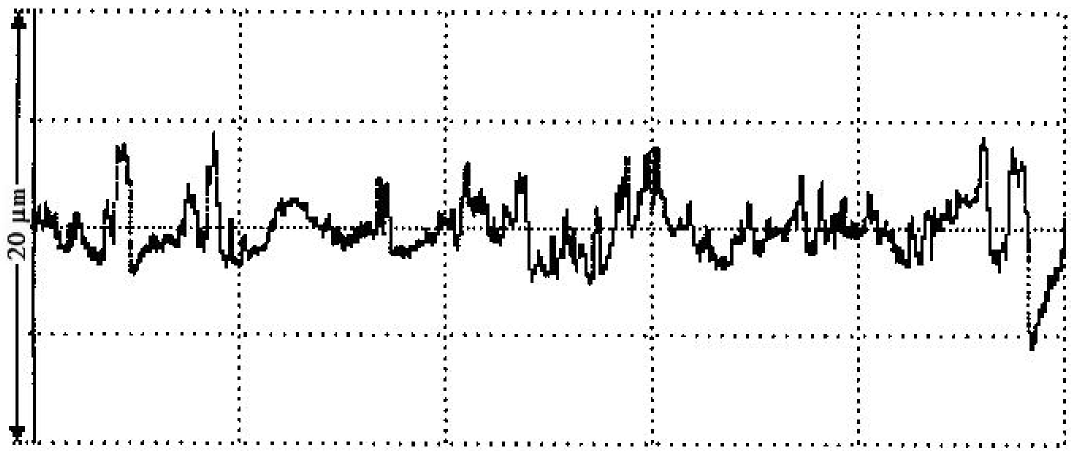



Fig.5. Surface roughness - $R_a$ parameter. Frictional pair: tool steel – titanium sheet a) tool surface with no layer, b) tool surface covered with Cr layer; friction distance *1m*, unit pressure *10 Mpa*.

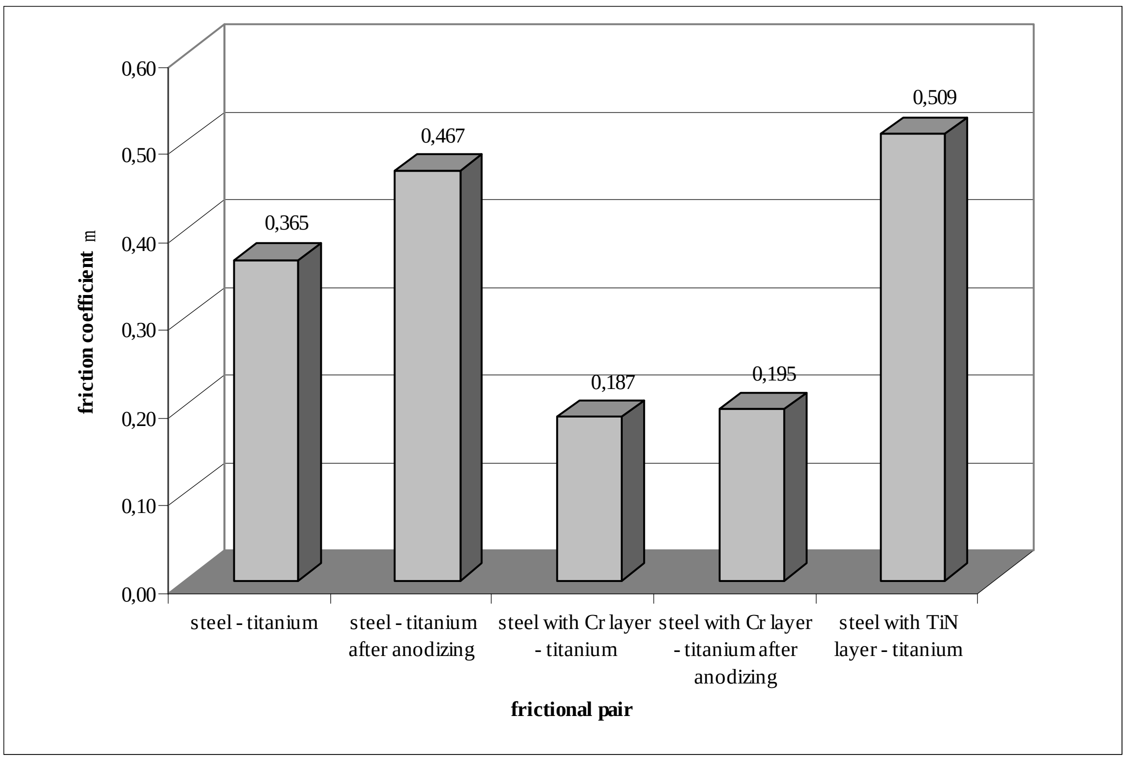



Fig.6. Comparison of the friction coefficients obtained in the "strip-drawing" test using steel inserts after different surfacing; dry condition, unit pressure $7.4\,MPa$.

## 5. Conclusions

It is possible to draw the following conclusions from the test results:

1. Titanium sheets are characterized by rather poor drawability because of the high yield point and high value of the $R_e/R_m$ ratio.
2. Titanium sheets show high frictional resistance and susceptibility to creation of titanium "build-ups" on the tool surface.
3. A the proper lubrication decreases frictional resistance. First and foremost, lubrication protects the tool from creation of „build-ups" – the main reason of adhesive wear.
4. The use of antiwear layers is the other method of adhesive wear prevention.
5. A chromium layer showed the best antiadhesive properties among the tested layers. A TiN layer did not affect a significant decrease in the value of the frictional coefficients for the tested sheets.

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