# COMPARISON OF SYMMETRIC AND ASYMMETRIC ROLLING FOR AA 5454 ALUMINIUM ALLOY*

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## Abstract

The study of asymmetric rolling on the AA 5454 aluminium alloy plates was carried out. The plates were taken directly from the industrial hot rolled sheet. They were cold rolled on the laboratory mill with different rotation speed of the upper and the lower work roller with the strains around 33 % and 44 %. To get closer to the industrial conditions the maximal dimensions of the rolled plates for laboratory rolling mill and the special industrial lubricant were used. After deformation the plates were annealed to the soft condition. This research was focused on all possible effects of asymmetric rolling: The reduction of rolling force, the increase of strain at same set roll gap, bending of workpiece, finer microstructure, more heterogeneous textures and as a consequence of that better mechanical properties. The asymmetric rolling with favourable mechanisms in the deformation zone has created the material with the homogeneous hardness in the cross section and with lower anisotropy, which is crucial for improvement of formability properties of aluminium work hardened alloys and to get closer to properties of steels. In the presented paper the general impact and different effects of speed difference of rollers was investigated on cold rolled aluminium alloy. Obtained and analysed results explain the function of asymmetry in rolling process and the options to implement the asymmetric rolling in industrial plant.

**Keywords:** Cold Asymmetric Rolling; Aluminium Alloys; Texture Characterization; Mechanical Properties.

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## 1 INTRODUCTION

Nowadays, the use of aluminium alloys in the automotive industry is increasing. Not just for different smaller parts, but has often, drawn a considerable attention to replace the steel in production of vehicle bodies. This is all regarding to lighter weight than steel, opportunity for less energy consumption of the vehicles and for that a cleaner environmental contribution, better corrosion resistance, and those are just some of many advantages. On the other hand, the limited commercial application and supressed potential to replace the steel counterparts are consequences of usually lower formability and higher planar anisotropy [1–4].

Cheon et. al. [5] discussed that the reasons for weakness of most aluminium alloys have been in its manufacturing process. That way also the improved research must be focused to production changes. With each metallurgical step in the manufacturing the microstructure and the texture of material changes. Both have significant influence on the mechanical properties of material. The process chain for most of current aluminium alloys sheets in use begins with the direct chill (DC) casting. Hirsch et. al. [6] states that casted texture will be very inexpressible with different recrystallized texture components, such as Cube {001}<100>, G (Goss) {110}<110>, R {124}<211>, P {011}<111> or Q {013}<231>. The uneven heat conditions as well as the low purity of liquid at solidification can create the predominant texture components with higher volume fraction. Han et. al. [7] proves that some textures may be present during some production processes that cannot be completely removed or changed by them. After casting the homogenisation annealing is next step. With them, beside the stress removal and the creation of microstructure homogeneity, the heat treatment was performed before metal forming with purpose to decrease possible dominant texture components and make the texture heterogeneous and more suitable for further metal forming processes. In principle the same texture components were created with hot and cold rolling. The strain has, in that case, larger influence than temperature but at the same time with hot rolling, due to higher stability, alongside rolling texture components are also expected more recrystallized texture components. Sidor et. al. [8] discusses that the rolling texture components, due to function of orientated flow among the metal forming, take the positions of the fibres. The α-fibre covers two texture components, previously mentioned G (Goss) and B (Brass) {011}<211>. The three texture components covered the positions for the β-fibre. As a consequence of several strains the β-fibre continues the α-fibre from B (Brass) to the S {123}<634> and C (Copper) {112}<111>. Because all texture components in both fibres are just partly stable and after subsequent or intermittent annealing became random, the idea of creation of shear texture components has appeared. With modification of rolling texture and production of some new texture components, the texture heterogeneity will increase and that will have positive influence on a decrease of planar anisotropy and increase of formability. The three shear texture components, H {001}<110>, E {111}<110> and F {111}<112>, last two also part of γ-fibre, can be produced with asymmetric rolling.

The performance of the asymmetric rolling is, in general, dependant of friction, kinetic or geometry. On that basics or fundamentals the four asymmetric rolling types are most common. Sidor et. al. [9] has performed the asymmetric rolling with different diameters of rollers. Wronski et. al. [10] provided the asymmetry in rolling process with difference in rotation speed of work rollers. Bintu et. al. [11] has performed the single drive roller, as type of the asymmetric rolling. Utsunomiya et. al.

[12] used differently lubricated work rollers surfaces to create the asymmetry in rolling process.

The laboratory symmetric and asymmetric rolling was performed on industrially produced AA 5454 aluminium alloy. The dimensions were maximal for laboratory rolling mill, the rest of conditions were chosen to be as similar as possible to the ones in industry. The advantages, of rolling with lower rolling force and reaching a higher strain have appeared with asymmetric rolling. Also the disadvantages, for example bended workpiece, were observed. The creation of microstructure and texture changes has been evaluated with different mechanical properties. The major attention was on improvement of planar anisotropy and possible negative changes at the expense of that.

## 2 MATERIAL AND METHODS

The industrial produced slabs of AA 5454 aluminium alloy were first directly chill cast and homogeneously annealed. Furthermore, hot rolling was performed to the thickness around 6.7 mm. From the hot rolled sheet the plates with dimensions of 510 mm x 230 mm were cut. On laboratory rolling mill asymmetry was created with the different rotation speed of upper and lower work roller (Figure 1). The upper roller always had the speed of 10 rpm, where the speed of lower roller changed from 10 rpm, 15 rpm and 20 rpm. The symmetric rolling type with the factor of asymmetry 1.0 and the two asymmetric rolling types with factor of asymmetry 1.5 or 2.0 were executed on two different roll gap sets. With the roll gap of 4.0 mm the strain around 33 % was reached and with the roll gap 3.1 mm the strain around of 44 % was created. The parameters of laboratory rolling are presented in Table 1. For each roll gap set and all symmetric and asymmetric rolling types the three plates were rolled to ensure repeatability and to produce enough material for all mechanical tests. The special lubricant SOMENTOR® was used to provide the industrial conditions as similar as possible. After cold rolling the heat treatment with 1 h on 400 °C heating was executed to reach the soft condition.

The samples for the tensile test and the plastic-strain-ratio test were taken in rolling, transverse and diagonal direction. From the Lankford factors ($r_0$, $r_{45}$, $r_{90}$), as ration between samples shrink and elongation, in different orientations, the normal anisotropy $r_m$ with equation:

$$r_m = (r_0 + 2 * r_{45} + r_{90})/4 \tag{1}$$

and the planar anisotropy $\Delta r$ with equation:

$$\Delta r = (r_0 + r_{90} - r_{45})/2 \tag{2}$$

was calculated. The Lankford factor *r* was acquired as average. Beside the tensile strength TS, yield strength YS and elongation, the hardening factor *n* was also calculated from stress-strain diagrams. Furthermore, the forming limit diagram FLD0 values were calculated with equation:

$$FLD0 = \ln\,[1 + (23.3 + 14.13 * t_0) * n * 0.21] \tag{3}$$

where the $t_0$ is the initial thickness of the sample. The Brinell hardness was measured on top, bottom and centre positions in the cross section, also the average grain size with light microscope (LM) and electron back scatter diffraction (EBSD) mapping with scanning electron microscope (SEM) was done on same positions.

**Figure 1:** Experimental part

**Table 1:** Experimental parameters

|  | Roll gap [mm] | Upper roller speed [rpm] | Lower roller speed [rpm] | Factor of asymmetry [/] |
|---|---|---|---|---|
| SIM1 | 4.0 | 10.0 | 10.0 | 1.0 |
| ASM1 | 4.0 | 10.0 | 15.0 | 1.5 |
| ASM2 | 4.0 | 10.0 | 20.0 | 2.0 |
| SIM2 | 3.1 | 10.0 | 10.0 | 1.0 |
| ASM3 | 3.1 | 10.0 | 15.0 | 1.5 |
| ASM4 | 3.1 | 10.0 | 20.0 | 2.0 |

## 3 RESULTS AND DISCUSSION

During rolling process the rolling force and the torque were measured. Lower rolling force was measured for all three rolling types with 4.0 mm set roll gap. Also the lowest strain was created with that set roll gap as with 3.1 mm. More important is that for both set roll gaps with asymmetric rolling types lower rolling force was needed to reach higher strains, as for symmetric rolling (Table 2). More exactly the 30 % at the SIM1 and the 31 % for ASM 1 and ASM 2 strain was reached. Similar as with higher set roll gap the differences in strain were also appeared with the lower set roll gap. The 43 % strain was reached for SIM2. 44 % and 45 % were been strains with ASM3 and ASM4. The production of higher strain with lower rolling force was a consequence of very evenly distributed stresses and strains in deformation zone [10]. Reaching higher strains for near 2 % just with one rolling pass can have significant influence on operating functions of rolling mill. Beside the smaller energy consumption and lower wear of rollers the time of rolling process is reduced [9]. The lowest torques have been measured with symmetric rolling types at both set roll gaps. With higher asymmetry also the torque has reduced but it was still higher as compared to symmetric rolling type.

**Table 2**: Maximal rolling forces for every condition

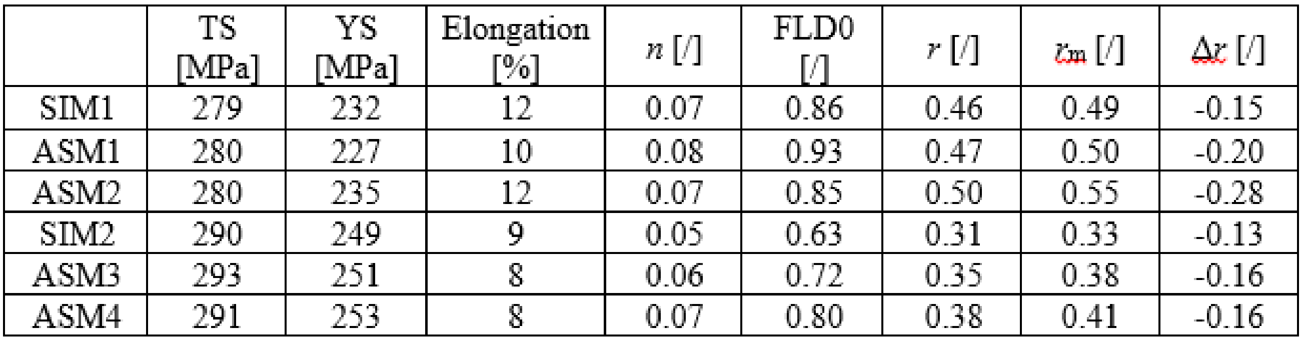
|  | Rolling force [kN] |
|---|---|
| SIM1 | 1128 |
| ASM1 | 1099 |
| ASM2 | 1082 |
| SIM2 | 1377 |
| ASM3 | 1341 |
| ASM4 | 1308 |

The bending of workpiece, known also as ski effect, has appeared just with asymmetric rolling. It is an unwanted phenomena and in some way presents useless material [11]. For further rolling operations the ski effect must be cut off or made flat. The coiling processes have, in greater extent, solved the problems with ski effect. The length and angles of ski effect was, in our case, quite similar. That was the consequence of the faster lower roller where the workpiece was rolled down on the rolling table. That way the formation of the larger ski effect was interrupted. Nevertheless the higher influence of the factor of asymmetry on the ski effect was observed, because the bended area was longer and with higher angle in cases of factor of asymmetry 2.0 as 1.5, independent of the roll gap set. Looking on the whole rolled plate the ski effect present from 5 % to 7 %.

The different mechanical tests were performed on the deformed (Table 3) and heat-treated (Table 4) samples, with the aim to track the changes between symmetric and asymmetric rolling. Although only one rolling pass was performed, the TS, YS and elongations, as results of tensile test, have stayed in the same range when comparing symmetric and asymmetric rolling. Higher FLD0 values were obtained at 4.0 set roll gap which is normal because with the 3.1 mm set roll gap higher strains were reached and the forming limits have been reduced. The major differences were observed at Δ*r*, where the values of asymmetric rolled samples for both set roll gaps will be more negative. That means that the material with higher planar anisotropy was produced with the asymmetric rolling, because the Δ*r* nearest to the 0 indicates lower planar anisotropy. The heat treatment brings the results of tensile test some more similarities. Practically no differences were obtained between TS, YS, elongations and *n*. Also the FLD0 values are quite similar with difference that the lower or higher reached strains influence was present also after heat treatment. In contrary as at deformed samples the Δ*r* values are at heat-treated samples less negative and consequently nearer to 0 at asymmetric rolling samples. With the 3.1 mm set roll gap the Δ*r* are just -0.05 for factors of asymmetry 1.5 and 2.0.

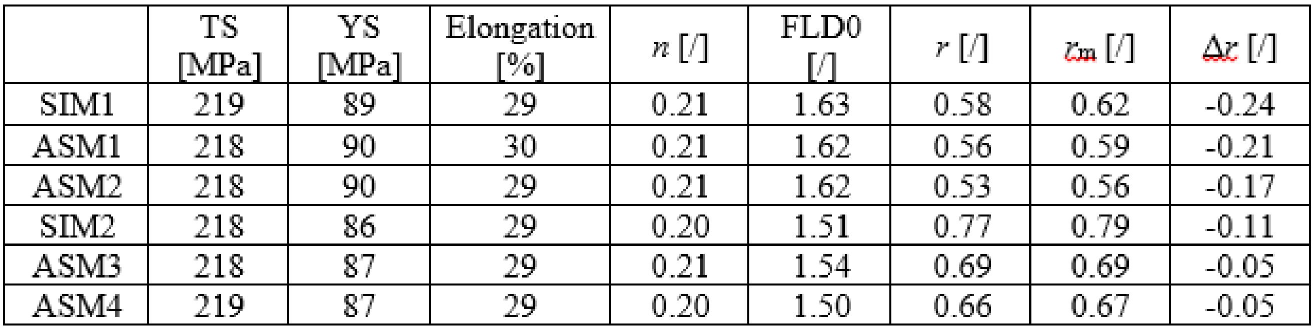
The Brinell hardness was measured as an additional mechanical test and values are presented in the Figure 2. The highest hardness has appeared in centre position in cross section but it is important to notice that like most other mechanical properties the hardness values are also very similar. In the Figure 2 the average grain size is also presented. The grains were smaller on the top and bottom position as in cross section what can be contributed by higher stresses and strains in those positions than in the centre. After heat treatment the grains have grown. When comparing the symmetric and asymmetric rolling microstructure latter produced smaller crystal grains. Also the influence of smaller grains was observed after heat treatment.

**Table 3:** Mechanical properties for the deformed condition

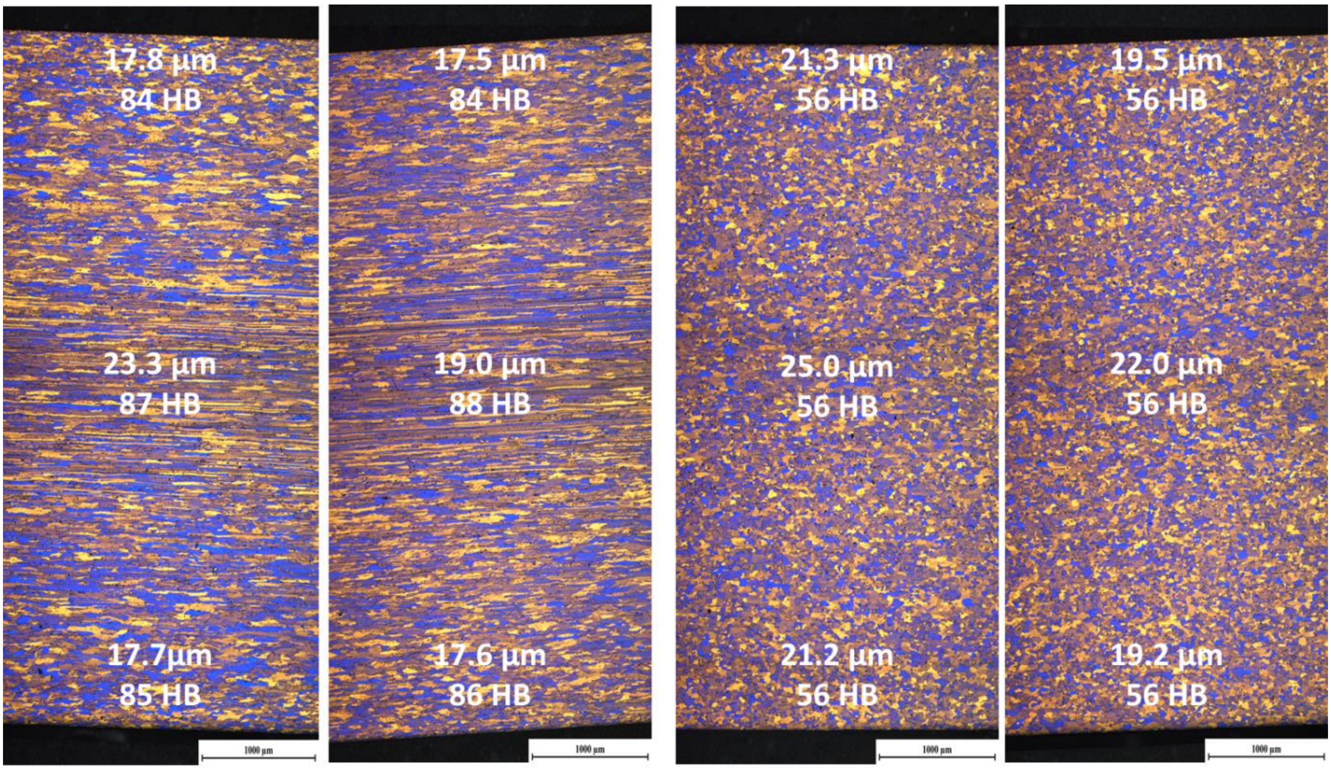


| | TS [MPa] | YS [MPa] | Elongation [%] | *n* [/] | FLD0 [/] | *r* [/] | $r_m$ [/] | Δ*r* [/] |
|---|---|---|---|---|---|---|---|---|
| SIM1 | 279 | 232 | 12 | 0.07 | 0.86 | 0.46 | 0.49 | -0.15 |
| ASM1 | 280 | 227 | 10 | 0.08 | 0.93 | 0.47 | 0.50 | -0.20 |
| ASM2 | 280 | 235 | 12 | 0.07 | 0.85 | 0.50 | 0.55 | -0.28 |
| SIM2 | 290 | 249 | 9 | 0.05 | 0.63 | 0.31 | 0.33 | -0.13 |
| ASM3 | 293 | 251 | 8 | 0.06 | 0.72 | 0.35 | 0.38 | -0.16 |
| ASM4 | 291 | 253 | 8 | 0.07 | 0.80 | 0.38 | 0.41 | -0.16 |

**Table 4:** Mechanical properties for the heat-treated condition



| | TS [MPa] | YS [MPa] | Elongation [%] | *n* [/] | FLD0 [/] | *r* [/] | $r_m$ [/] | Δ*r* [/] |
|---|---|---|---|---|---|---|---|---|
| SIM1 | 219 | 89 | 29 | 0.21 | 1.63 | 0.58 | 0.62 | -0.24 |
| ASM1 | 218 | 90 | 30 | 0.21 | 1.62 | 0.56 | 0.59 | -0.21 |
| ASM2 | 218 | 90 | 29 | 0.21 | 1.62 | 0.53 | 0.56 | -0.17 |
| SIM2 | 218 | 86 | 29 | 0.20 | 1.51 | 0.77 | 0.79 | -0.11 |
| ASM3 | 218 | 87 | 29 | 0.21 | 1.54 | 0.69 | 0.69 | -0.05 |
| ASM4 | 219 | 87 | 29 | 0.20 | 1.50 | 0.66 | 0.67 | -0.05 |



Symmetric rolled
Deformed condition

Asymmetric rolled
Deformed condition

Symmetric rolled
Heat-treated

Asymmetric rolled
Heat-treated

**Figure 2:** LM microstructures of rolled plates in cross section

The reasons for reduction of the planar anisotropy of asymmetrically rolled samples after heat treatment were searched for in textures. Comparing pole figures (Figure 3), as texture presentation, quite a lot of similarities can be observed. But most importantly the intensity of texture is steadily decreasing with higher factor of asymmetry. More exactly, the intensity of texture was reduced from 3.29 at SIM1 to 2.85 and 2.05 for the ASM1 and ASM2. Each texture component is defined with own crystallographic plane and direction. The intensity of the texture has direct correlation to the domination of some separate texture components in the texture. The mentioned is also in accordance with the texture heterogenity which is wished phenomena for lower planar anisotropy [9]. For lower anisotropy is important that in texture were detected as much as possible different texture components, because that were been indicator that properties are distributed in all crystallographic planes and directions of texture components. Previously stated stands-out or better said; dominant texture components are especially clearly visible with symmetric rolling where the texture component E and texture component G have significantly higher volume fraction as all other texture components. In comparison to the both asymmetric rolling types where the volume fractions of all texture components are much evenly distributed the described phenomena can be a major reason for the reduction of planar anisotropy. With asymmetric rolling more shear deformation and that way also more shear texture components were been created. In consequence the asymmetric rolling is very successful with reduction of planar anisotropy because more diverse texture components were created and stayed also after heat treatment.

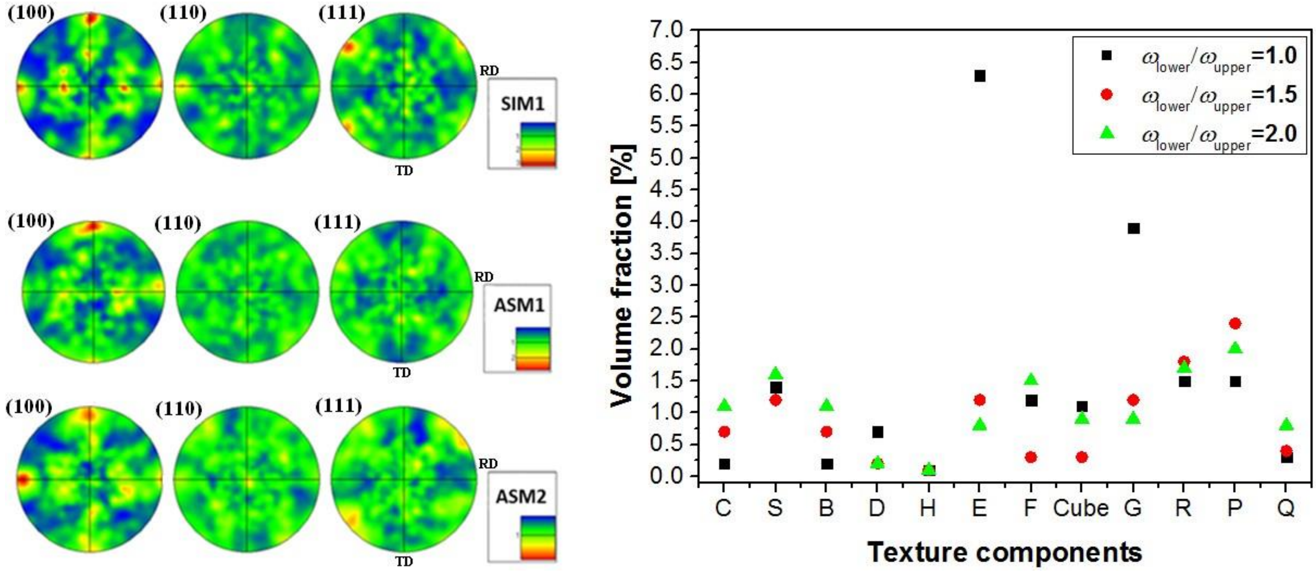


**Figure 3:** Texture presentation with pole figures and graph of texture components volume fraction

## 4 CONCLUSION

In summary, the ingot of work hardened AA 5454 aluminium alloy was industrially produced with direct chill (DC) casting and hot rolled to the sheet. Furthermore, the symmetric and asymmetric cold rolling was performed on laboratory rolling mill. The difference of rotation speed resulted in reaching almost 3 % higher strains with 70 kN less rolling force only with one rolling pass. The improvement of mechanical properties was best shown among planar anisotropy. The almost total elimination of higher planar anisotropy, like for symmetric rolling after deformation, has appeared at asymmetrically rolled samples after heat treatment to the soft condition. The desired phenomena was a consequence of texture heterogeneity and even distribution of texture component's volume fractions. The special ski effect accompanying asymmetric rolling is a product of the bending of workpiece. In the industrial plant the stated problems can be solved with the direct coiling of rolled material which will decrease the number of extra operations for flattening the workpiece.

## Acknowledgments

The authors acknowledge the financial support from the Slovenian Research Agency, research corefundings No. P2-0132 and No. P2-0344. This work was also funded by the program MARTINA, supported by Slovenian Ministry of education, science and sport and European Regional Development Fund.

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