

Evaluation of the impact of the natural seasoning process on post-machining deformation of thin-walled elements made of aluminium alloy EN AW-2024

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Abstract. The study attempts to evaluate the impact of short-term natural seasoning process on the state of post-machining deformations of thin-walled elements made of the EN AW-2024 aluminium alloy. Analyses were made of the impact of the technological history of the semi-finished product, in this case – the rolling direction of the plate (perpendicular and parallel to the feed direction) as well as high-performance machining strategies, such as High Speed Cutting (HSC) and High Performance Cutting (HPC) on the value of deformations of thin-walled samples, directly after machining and after seasoning. Application of natural seasoning at reducing deformations of thin-walled elements made of aluminium alloys may prove an alternative to the difficult intermediate heat treatment. The expected reduction of deformations is a result of reducing residual stresses in the material, in the course of the relaxation process. The dynamics of the natural relaxation is highly correlated with the properties of materials. The study includes an analysis of the effects of a short-term relaxation, accepted in industrial conditions (up to 1 month since the end of machining) for the EN AW-2024 alloy. If the proposed solution gives positive effects, it can bring measurable economic benefits in industrial applications. The study is completed with general and practical conclusions.

1. Introduction

Problematic non-dilatational strains are observed after machining of thin-walled elements made from monolithic, rolled plates and removing them from the machine grip. The resulting post-machining deformations depend on many factors, including e.g. properties of the workpiece material, method of fastening and residual stresses, which result from the state of the technological surface layer. In order to minimize residual stresses, it is recommended, among others: stress relief annealing, low-temperature tempering and seasoning [5], [7], [9], [21], [22]. The mechanism of creating residual stresses during machining is a result of the mechanical and thermal impact, stemming from e.g. permanent changes in the crystal lattice, phase transitions and the occurring temperature gradients. The applied technological parameters, such as: depth of cut, cutting speed, feed, tool type, its geometry and degree of wear as well as cooling conditions have impact on intensification of formation process of residual stresses and their final state [3], [4], [6], [13], [14], [17], [23]. The authors of studies [7], [9], [12] claim that post-machining deformations of thin-walled elements result in residual stresses generated both during the manufacture of a semi-finished product and the machining process. During annealing, the basic mechanism causing the reduction of stresses is relaxation defined as “spontaneous reduction of tensions in a metal material”, strongly correlated with the material's



properties and resulting from dislocation slippage (connected with the common motion of a group of atoms) and diffusion (connected with the individual motion of atoms). Relaxation of residual stresses in metals is an exceptionally complex issue, depending on many factors connected both with the given material and the process parameters (i.e. time and temperature). The engineering industry, aviation in particular, is constantly searching for new solutions to eliminate the additional, intermediate heat treatment which significantly increases costs and reduces manufacturing efficiency [8], [11], [17], [20].

The production of thin-walled elements from rolled plates requires an intensified machining process. Therefore, a dynamic development of two high-performance machining technologies has been recently observed in the machining industry: High Speed Cutting (HSC) and High Performance Cutting (HPC). High Speed Cutting is defined as machining using very high rotational speeds of the tool, which in turn increases the cutting speed. The characteristic feature of this method are also smaller cross-sections of the machined layer compared to conventional machining. It is important that in range of technological parameters of HSC, the increased machining speed causes a reduced cutting force. HPC is applied mainly in order to raise chip volume, i.e. the volume of the removed material per time unit. This is possible due to applying higher cutting speed and bigger cross-sections of the machined layer (depth of cut, milling width, feed per tooth) than during conventional machining methods. It is assumed that HSC is used as finishing machining, while HPC is used as roughing or semi-finishing, however, it must be noted that there is no clear distinction between them [1], [2], [10], [15], [16], [18], [19], [24].

This study focused on the analysis of the impact of two-weeks of seasoning of flat, thin-walled samples made of the EN AW-2024 aluminium alloy on post-machining deformations.

2. Methodology

The purpose of the study was to evaluate the usability of the natural, short-term seasoning as a method of reducing post-machining deformations of thin-walled elements. The machined material was the EN AW-2024 aluminium alloy (chemical symbol: EN AW-AlCu4Mg1), subjected to heat treatment (T351), which is one of the most common multi-component alloy, used widely e.g. in aviation, due to its high strength and relatively low mass density. Its chemical composition is shown in Table 1. The machining was performed using an Avia VMC 800HS 3-axis machining centre with a Heidenhain iTNC 530 control.

Table 1. EN AW-2024 alloy chemical composition.

EN AW- 2024	Chemical composition [%]										
	Si	Fe	Mg	Cu	Mn	Zn	Cr	Zr	V	Ti	Other
	0.07	0.20	1.3	4.6	0.56	0.11	0.01	0.01	0.01	0.02	0.05
Alloy limits [%]											
min	0.00	0.00	1.20	3.80	0.30	0.00	0.00	0.00	0.00	0.00	0.05
max	0.50	0.50	1.80	4.90	0.90	0.25	0.10	0.05	0.05	0.15	0.15

Two milling cutters were used for the purpose of the research:

- indexable end milling cutter of Kennametal (symbol: 25A03R044B25SED14) with carbide inserts (symbol: EDCT140416PDFRLDJ) – used for HPC,
- monolithic carbide milling cutter of Sandvik (symbol R216.33-16040-AC32U H10F) – used for HSC.

Measurements of post-machining deformations were made using a digital sensor Sylvac CL44 L = 36.5 with measuring pressure equal 0.07 N. Measurements were performed after removing the clamping force. The simplified design of the experiment is presented in Figure 1. As part of the research, a flat sample with overall dimensions 10x45x210 mm was machined. Independent variables included the machining strategy, the rolling direction and the use of natural seasoning, while the dependent variable – post-machining deformations. Among the fixed factors were: the EN-AW 2024 aluminium alloy and the work environment.

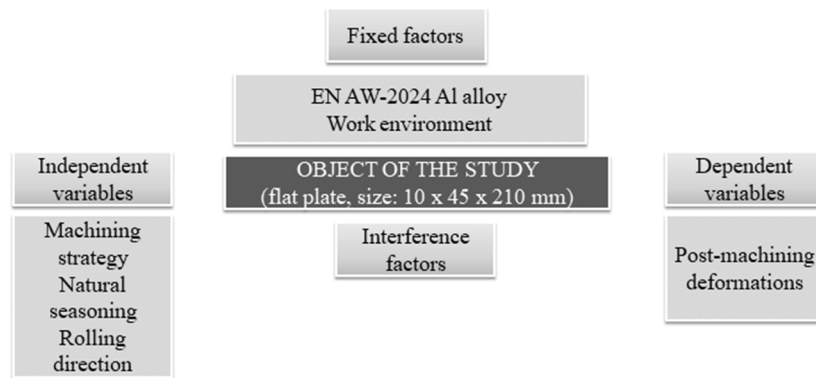


Figure 1. Design of the experiment.

Modern, high-performance technologies called machining strategies were applied in the research:

- High Performance Cutting (HPC),
- High Performance Cutting and High Speed Cutting (HPC/HSC),
- High Speed Cutting (HSC).

Table 2 shows values of technological parameters in individual milling strategies.

Table 2. Values of technological parameters in individual milling strategies.

Technological parameters	Strategy			
	HPC	HPC/ HSC		HSC
		HPC	HSC	
Depth of cut a_p [mm]	4.5	4.3	0.4	0.95; 0.45*
Milling width a_e [mm]	18.75	18.75	12	12
Cutting speed v_c [m/min]	1 000	1 000	1 200	1 200
Feed per tooth f_z [mm/tooth]	0.1	0.1	0.02	0.02
Rotational speed n [rpm]	12 732	12 732	23 873	23 873
Feed rate v_f [mm/min]	3 820	3 820	1 432	1 432
No. of passes i [-]	2	2	1	9; 1*

* Final pass

The second independent variable adopted was the rolling direction:

- parallel to the direction of tool feed (longitudinal direction),
- perpendicular to the direction of tool feed (transversal direction).

Moreover, in order to check the impact of seasoning on post-machining deformations of the given thin-walled elements, additional deflection measurements for all configurations were measured after

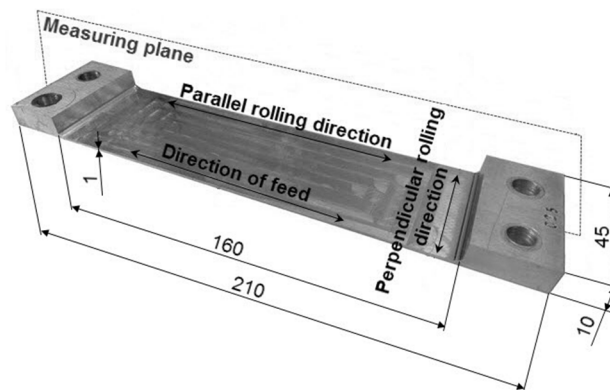


Figure 2. Sample view after machining.

two weeks. Samples were stored in a university laboratory room in a designated place, in temperature 22–24°C. Sample view after machining is shown in Figure 2. Its overall dimensions were: 10x45x210 mm, relief length – 160 mm, target bottom thickness – 1 mm.

Figure 2 includes marked correlations between rolling directions and the directions of tool feed as well as the position of the plane, where measurements were made using a digital sensor Sylvac.

3. Results

The evaluation of results began with the analysis of deformations in samples where the rolling direction was parallel to the direction of feed. A summary of deformation values was made, directly after machining and after seasoning, for three strategies: HPC, HPC/HSC and HSC. Figure 3 shows a comparison of deflection f , measured along the measuring section I of the samples, directly after machining and after two weeks of natural seasoning, obtained for the parallel rolling direction and the three strategies: a) HPC, b) HPC/HSC, c) HSC. The maximum deflection values are respectively: HSC: $f_{\max} = 0.241$ mm (after machining), $f_{\max} = -0.173$ mm (after seasoning), HPC/HSC: $f_{\max} = -0.128$ mm (after seasoning), $f_{\max} = -0.218$ mm (after seasoning), HSC: $f_{\max} = -0.045$ mm (after machining), $f_{\max} = -0.190$ mm (after seasoning). The (-) sign next to bend deflection values indicates displacement below the agreed reference plane. Based on the presented results, it was observed that for the HPC/HSC combination and the HSC technology after seasoning, an increase of deformations occurred, while it significantly decreased in the case of HPC.

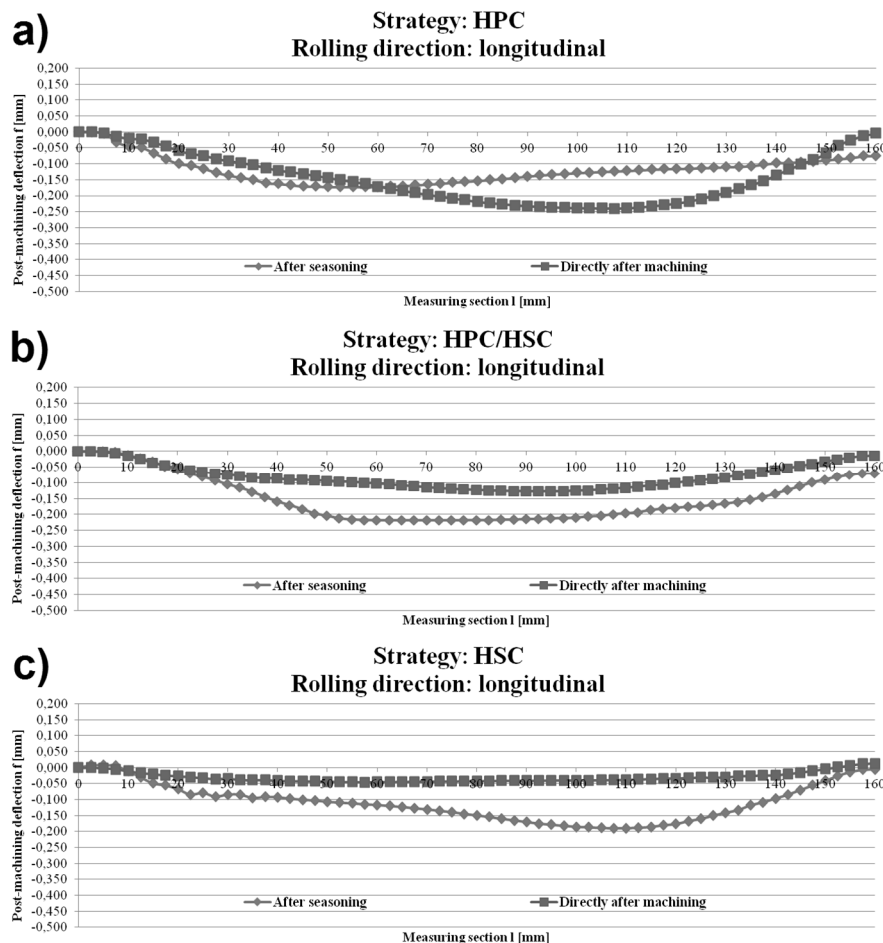


Figure 3. Deflection f , measured along the measuring section I of the samples, directly after machining and after two weeks of seasoning – parallel rolling direction and the three strategies: a) HPC, b) HPC/HSC and c) HSC.

In the next stage, the research results were analysed for the perpendicular rolling direction in relation to the feed direction, directly after machining and after seasoning. Figure 4 shows the comparison of deflection f measured along the measuring section I of the samples, directly after machining and seasoning, obtained for the perpendicular rolling direction and the three technologies: a) HPC, b) HPC/HSC, c) HSC. The obtained maximum deflection values are: HSC: $f_{\max} = 0.335$ mm (after machining), $f_{\max} = -0.509$ mm (after seasoning), HPC/HSC: $f_{\max} = -0.155$ mm (after machining), $f_{\max} = -0.295$ mm (after seasoning), HSC: $f_{\max} = -0.142$ mm (after machining), $f_{\max} = -0.309$ mm (after seasoning). Based on the obtained results, it was observed that an increase in deformations occurs for each strategy after seasoning.

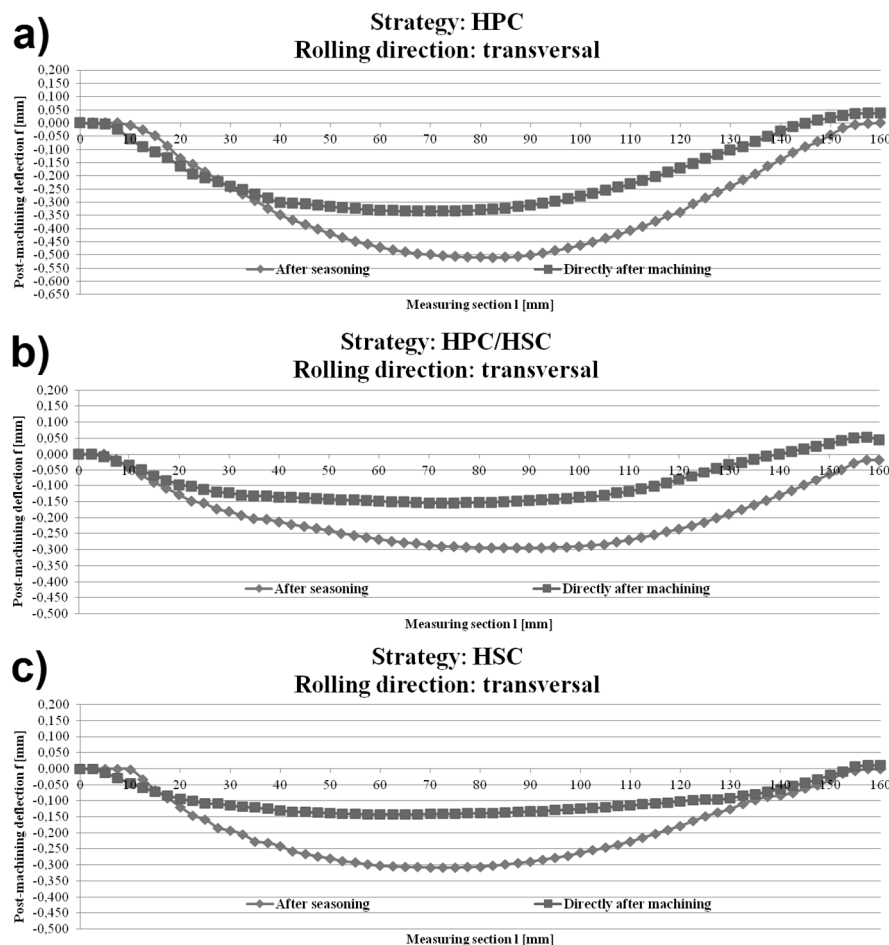


Figure 4. Deflection f , measured along the measuring section I of the samples, directly after machining and after two weeks of seasoning – perpendicular rolling direction and the three strategies: a) HPC, b) HPC/HSC, c) HSC.

The comparison of maximum deflection values directly after machining and after seasoning, for the three analysed strategies and parallel rolling direction is shown in Figure 5.

For perpendicular direction and the three analysed strategies, also the comparison of maximum deflection values directly after machining and after seasoning was made and is shown in Figure 6.

Based on the presented research results, it was observed that the application of natural seasoning for the duration of two weeks results in an increase of the post-machining deformation values of thin-walled elements made of the EN AW-2024 aluminium alloy. Only in the case of the HPC strategy and parallel rolling direction, a slight decrease of the said values was observed.

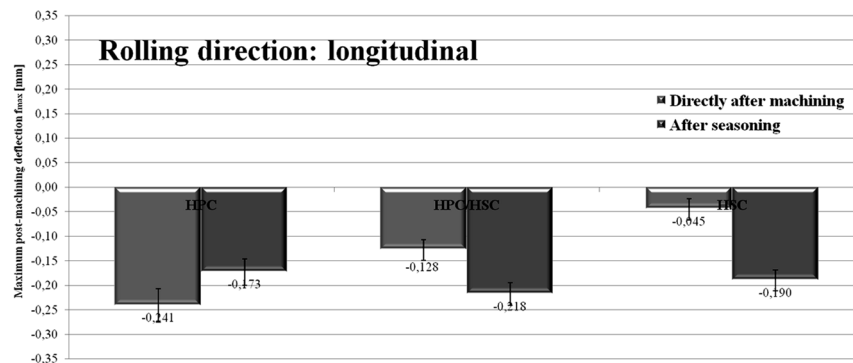


Figure 5. The comparison of maximum deflection values f_{\max} directly after machining and after two weeks of seasoning for parallel rolling direction.

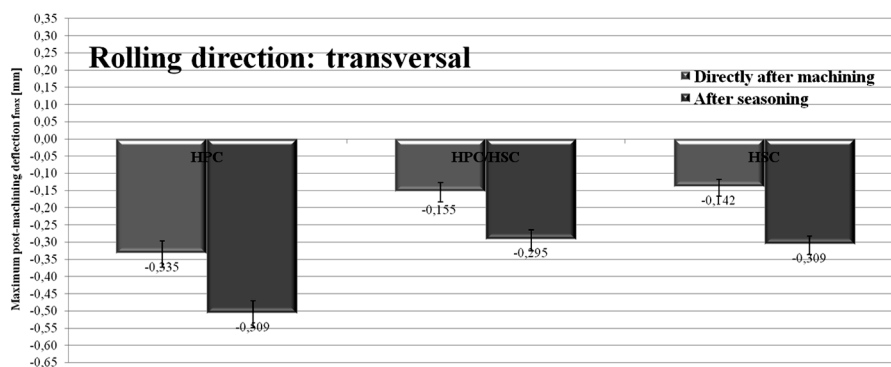


Figure 6. The comparison of maximum deflection values f_{\max} directly after machining and after two weeks of seasoning for perpendicular rolling direction.

4. Conclusion

The performed analysis of the measurement results leads to the following practical and general conclusions: After two weeks, in the samples subjected to milling parallel to the rolling direction, an increase of deformations occurred in the case of the HPC/HSC combination and the HSC technology, while the deformations decreased in the case of HPC; After two weeks of natural seasoning, in the samples machined perpendicularly to the rolling direction, an increase of deformations was observed for each strategy; Based on the obtained research results, it was concluded that the application of natural seasoning for the duration of two weeks does not reduce post-machining deformations of thin-walled elements made of the EN AW-2024 aluminium alloy; A probable cause of the observed results is an insufficient seasoning period. It turns out that the relaxation process of post-machining tensions has a complex nature and additional, specialised research is necessary to learn about those mechanisms; The existing deformations are strictly connected with the relationship of the rolling direction of the semi-finished product to the feed direction during machining.

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