THE SHEAR STRENGTH ON THE WOOD/BARK BORDER OF SESSILE OAK

Peter Vilkovský – Igor Čunderlík – Vladimír Račko

Abstract

Bark as a component of a living tree represented a complex structure which significantly influenced the physical and mechanical properties. Bark as part of the tree must be the most effective and most perfectly removed in practice. We came across of these problems mainly in the pulp and paper industry. Research based on values of shear strength in a particular month confirmed that best used for debarking process is the tangential direction. Measurement proved that the most important factors influencing the resulting value of shear strength are wood/bark moisture and the vegetation period. Shear strength fluctuated with fresh state of 300 to 350 % lower as a dry state in each direction of load. Shear strength were more than 90 % in the fresh state and a longitudinal direction higher than in the tangential direction. The most appropriate and effective for period removing bark in the tangential direction and fresh state shall be considered of months July, August, March, April and May.

Key words: *Bark, Sessile Oak, Shear Strength, Vegetation period, Debarking*

INTRODUCTION

Bark, as a product of wood and cork cambium division, differs significantly from the secondary wood, which is also a product divided by wood cambium. It is known that all types of wood have their own characteristics (BAROTH 2005). The difference in the structure of wood and the bark is expressed at significant levels of physical, mechanical and chemical properties. This is the main reason why in many wood processing technologies debarking takes its place. Particularly in the processing of wood pulp and paper industry bark is undesirable in semi-products or final products (pulp, paper) (DRUMMOND 2004). Looking at the bark as an undesirable proportion of wood (logs), it is important to know the adhesion on wood.

Sessile oak represents high percentage (10.6 %) in our forests, after beech with 33 % oak is the second most represented tree species in Slovak forests (ZELENÁ SPRÁVA 2015). Oak as a ring-porous wood is used mainly in the pulp and paper industry and represents a significant proportion of processed raw material (about 16 %). In the pulp and paper industry perfect debarking is a requirement.

In the view of debarking it is known that logs are easily debarked only when the adhesion at the interface of the wood/bark is at low value. This in turn increases the possibility of removing the bark and thus reduces the percentage of remaining bark on debarked log. Therefore, we can declare, that the main criterion for debarking process is

Technical University in Zvolen, T. G. Masaryka 24, 960 53 Zvolen
e-mail: petervilkovsky38@gmail.com, igor.cunderlik@tuzvo.sk, racko@tuzvo.sk

wood/bark adhesion (BAROTH 2005). Adhesion of wood/bark is influenced by several important factors such as moisture content, ambient temperature, storage period, woody species and bark type, wood density and bark density.

When debarking in drum debarker, it is needed to optimize debarking degree to reduce the wood loss. Many studies looked into wood/bark adhesion. They assessed a shear strength on wood/bark interface in debarking process in drum debarkers, used mainly in the pulp and paper industry (BAROTH 2005, CHOW AND OBERMAJER 2004, ÖMAN 2000). In their research, they analysed the factors influencing the final value of adhesion. BAROTH (2005) and ÖMAN (2000) in their study found that the moisture content is the most important factor wood/bark adhesion. ÖMAN (2000) states that the lowest values of shear strength on wood/bark interface were measured especially when logs were fresh. The highest values were measured on the wood that was air dried.

Studies of several authors (BAROTH 2005, CHOW AND OBERMAJER 2004) were aimed at monitoring the effect of storage time on logs wood/bark adhesion. CHOW AND OBERMAJER (2004) claimed that infringement of inner bark occurs on greatly dried logs. This fact leads to an increase in bark content in the pulp chips. Another researches DUCHESNE AND NYLINDER (1996) showed that shear strength between the bark and the wood has not changed during the first six weeks of storage. Shear strength was significantly increased only when the moisture content drops below 40%. Moisture content of 30 % is considered as the critical moisture content of maximum shear strength.

Significantly higher content of bark in wood chips is in winter when a lot of log are imperfectly debarked. The issue of debarking of frozen logs will be devoted (BEDÁRD A LAGANIÉRE 2009 LAGANIÉRE A BEDÁRD 2009). The results of these studies showed that the wood/bark interface shear strength is higher at lower temperatures (-30 °C) than at higher temperatures (20 °C). On the other hand, the results also showed that at a temperature of 5 °C same debarking quality, as in the summer, can be achieved. LAGANIÉRE A BEDÁRD (2009) also found that during the winter months, it is appropriate preheating logs by infrared radiation, which facilitates the process of debarking.

An important factor influencing the final wood/bark adhesion is the structure of bark, or more precisely cambium and bast structure. Structure of oak bark was studied by many authors (GRIČAR ET AL. 2015, QUILHÓ ET AL. 2013, SEN ET AL. 2011, GRIČAR 2010, TROCKENBRODT 1995 1994 1991 1990, HOWARD 1977, HOLDHEIDE 1951) and they focused their study on morphological composition of the inner (bast) and the outer bark (rhytidome). Oaks are characterized by thick bark with longitudinal-transverse cracks. GRIČAR ET AL. (2015) studied the structure of oak bark *(Quercus petraea* Liebl.*)*. Mentioned authors divided cortical tissues sessile oak into zones of non-collapsed inner bark, collapsed inner bark and rhytidome. The inner bark is composed of sieve tubes, bast fibres, sclereids, axial and a beam supporting parenchyma and parenchymal cells. However, the outer bark is made up only from dead tissue of periderm and bast. HOWARD (1977) attributed the mechanical function of oak bark to two types of cells, bast fibres and sclereids. HOLDHEIDEA (1951) described annual bast growth as a layer consisting of sieve tubes, bast fibres, as well as supporting cells of the axial parenchyma and ray parenchyma.

EINSPAHR ET AL. 1971, HARDER ET AL. 1977 discussed the measurement of wood/bark adhesion (shear strength) (Fig. 1, 2). The measurement was taken during the growing and dormant period in the longitudinal direction. Failure of the bark were observed during the growing period came with small variations in cambial zone. At a time when cambium has entered dormant state a failure of the bark began to move into the zone phloem.

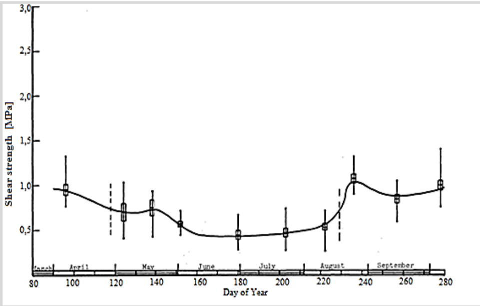

Fig. 1 Seasonal variation in shear strength for *Quercus macrocarpa.* The vertical dashed lines indicate the eastimated start and end of growing season (EINSPAHR ET AL. 1971).

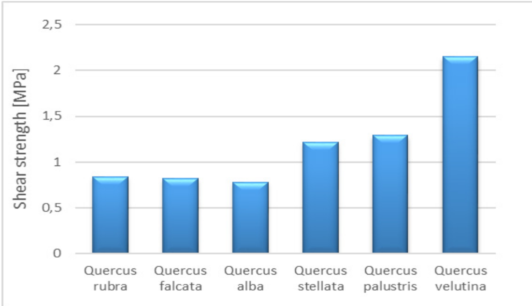

Fig. 2 Values of wood/bark shear strength In longitudinal direction (HARDER ET AL. 1977).

Holes of the rays on the xylem side and the remnant phloem on the phloem side were characteristic for the failure zone during the period of active cambium. Tests showed that oak bark is relatively fragile and during the dormant period can adhesion of bark on a tree increased by bast rays. Problems in debarking process in the dormant period may be caused by multiseriate rays and bark fragility, which impairs the removal of the larger units (EINSPAHR ET AL. 1971).

EXPERIMENTAL

MATERIALS AND METHOD

Measuring of shear strength at the interface wood/bark of oak (*Quercus petraea* (Matt.) Liebl.), were found from cut off samples. Samples were selected monthly from three tabs. Removal process was carried out of monthly intervals from July to May. Samples were located in Včelien in Kremnica Hills (450 m.a.s.l.) belonging to University forest holdings (VšLP) of the Technical University in Zvolen. The sampling area was characterized by mixed stands (hornbeam, oak, beech). Three samples were cut off, (Fig. 3) on which health status was initially assessed. For each sample in breast height about 1.3 meters two discs (samples) were cut off with thickness about 50-60 mm (Fig. 4). The diameter of selected trees varied from 30 to 35 cm, which represents approximately 100–110 years. The first sample was used to form test pieces for the shear strength tests on wood/bark interface in the axial (longitudinal) direction and second sample in the tangential direction. The samples were cut from test specimens (Fig. 3), to test the shear strength wood / bark in the tangential (T) and the axial direction (L) of dimensions 30 x 30 mm (L x T). Surface of shear (bark), was divided into two equal segments, which were used to test the shear strength of fresh and dry state.

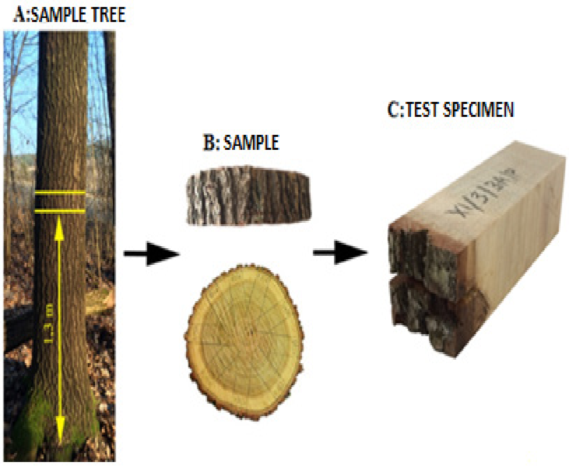

Fig. 3 Sequential steps to get the testing sample

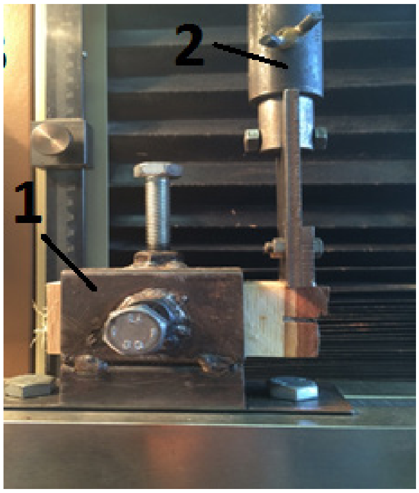

Fig. 4 Depiction test specimen an anchored by screws (1) and the jaw edges on the different interfaces wood/bark (2)

Specimens were tested in the fresh state and then placed in a room air conditioner, which have been conditioned under ambient conditions (t = 20 °C and φ = 65 %) corresponding to the equilibrium moisture content about 12 %. Shear testing was performed on the Ripper (Fig. 3). Fixing the test specimen was carried out with anchored by screws. Ripper includes mechanical arm containing special jaw with different edges, which served for the best possibility to follow a layer between the wood and bark (Fig. 4). The principle of measurement was based on strength needed for break off the bark from the wood surface. Using the scan tool connected, the changing force was recorded during the measurement as an output voltage corresponding to the amount of force at the moment of measurement. The dimensions of test area on specimens were measured before testing (height × width of the bark). Afterwards, premeasured test specimen were put in the ripper and fixed in by the anchored screws.

Subsequently, recorded values were evaluated by macros for tested specimens individually. Measured cortex dimensions corresponding to test specimen and output voltage were used for evaluation. The shear strength value of each specimen was calculated by equation (1). The same measurement procedure was applied to the air-conditioned units. The determination of bark adhesion through limit of shear strength:

$$\tau_{t/l} = \frac{F}{S} \quad \text{[MPa]} \qquad (1)$$

Where: $\boldsymbol{\tau_{t,l}}$ *– limit of shear strength in the longitudinal and tangential direction [MPa]* ***F*** *–maximum loading force [N],* ***S*** *- shear area [mm2].*

Last part of the research was the microscopic analysis of the cambial zone and phloem during dormant and growing season. The main thrust of this analysis was to determine the quality and quantity of cambial zone in different periods of year, and to see the phloem cell composition in oak. When analysing we used the permanent and temporary preparations.

TREPHOR (ROSSI ET AL. 2006) was used for sampling of bark, cambium layers, phloem and wood.

This device allowed us to in FAA (formaldehyde–acetic acid–ethanol) fixative solution for 2 days. After two days, the samples were removed from the fixative and transferred to a dissolved substance polyethylene glycol (PEG 1500).

For better understanding the morphology of the bark, which is much more complex than in wood, we had to delignification the bark layers. GARTNER, SCHWEINGRUBER (2013) method was used for preparation of macerate, who suggested a mixture of three components: hydrogen peroxide 32 %, concentrated sulfuric acid and water in a ratio of 1: 1: 1.

RESULTS AND DISCUSION

Values of the shear strength showed that the interface wood/bark on the sessile oak are different in particular depending on the vegetation alternatively dormant period. Results shear strength confirmed this fact. The highest values were achieved during the dormant period, mainly in the months of September (0.39 MPa - tangential direction and 0.80 MPa in the longitudinal direction) (Fig. 5, 6). The measurements EINSPAHR ET AL. (1971) were similar with our values shear strength which is measured in April and May. The results demonstrated a significant effect of wood and bark moisture which the resulting value of shear strength affected. Studies of BAROTH (2005) and ÖMAN (2000) corresponded with our assertions and moisture put the most important thing to factor influencing the resulting value of shear strength. Our values showed that not occurs at debarking in the fresh state significantly the bark a resistance against secession. The shear strength increased significantly when air conditioning the bark and wood (w = 12 %). For values shear strength in the longitudinal direction we recorded an increase in some months by nearly 350 %. A similar development, increased by 300 % we noticed in the tangential direction. The studies CHOW, OBERMAJER (2004) and NYLINDER ET AL. (1995) confirms this. The authors observed that occur a significant increase in shear strength of air conditioning logs.

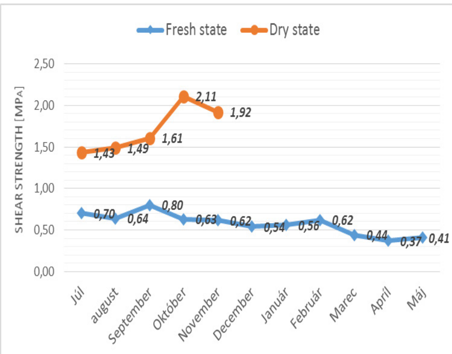

Fig. 5 Average values of shear strength measured fresh and dry state in the longitudinal direction on sessile oak the months during the year

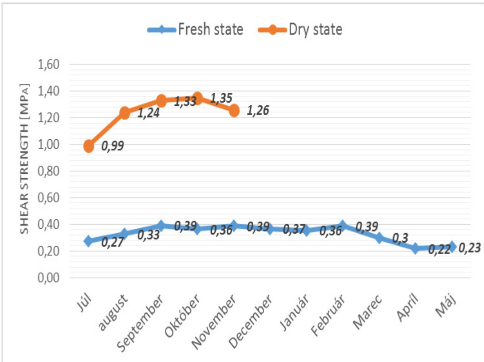

Fig. 6 Average values of shear strength measured fresh and dry state in the tangential direction on sessile oak the months during the year

The failures bark were observed of minor variations in cambial zone, especially during the growing season. Failure zone has gradually started to transfer deeper into the inner bark (phloem) in the dormant period. This behaviour can be attributed also zone cambium, which differed significantly particularly in quantity and quality of cells during the dormant and growing season. Our images this argument confirmed where we focused on the phloem and cambium zone. Our observations showed that cambium zone contained significantly smaller number cells during the dormant period as compared to the growing season (Fig. 7a, b). We also noticed that the cambium zone varies the thickness of the cell wall in the transition from the dormant to growing period. EINSPAHR ET AL. (1971) and HARDER ET AL. (1977) indicated similar explanation. They also determined that in particular may increase adhesion wood/bark also phloem rays in dormant period. Pursuant to the said authors, these are the main factors that brought worse debarking logs in dormant period.

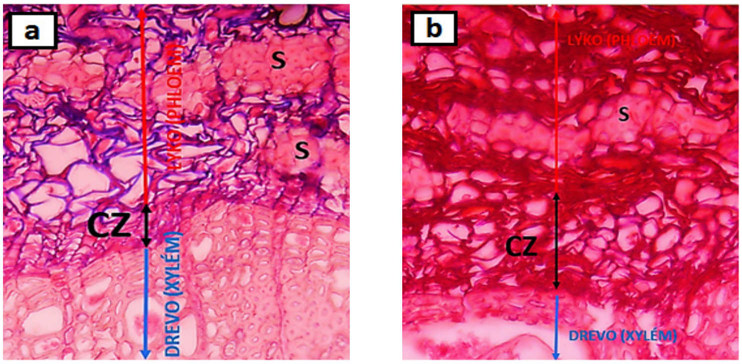

Fig. 7 Cross section showing the interface wood-phloem-cambium during dormancy (a) and growing (b) period for sessile oak tree species – S : sclereids, CZ : cambial zone

On the shear strength can affect the resulting value the structure of bark, better said phloem. In accordance with our observations which correspond with the findings GRIČAR ET AL. (2015) and HOWARD (1977), the phloem of oak consists mainly thin wall sieve tubes, resembling early vessels, thick-walled phloem fibres, accompanying parenchymal cells (rays, accompanying etc.) and sclereids (stone cells) (Fig. 8). We can conclude that the mechanical function, in accordance with morphology of cells in the phloem zone in oak bark has a significant impact especially phloem fibres and sclereids.

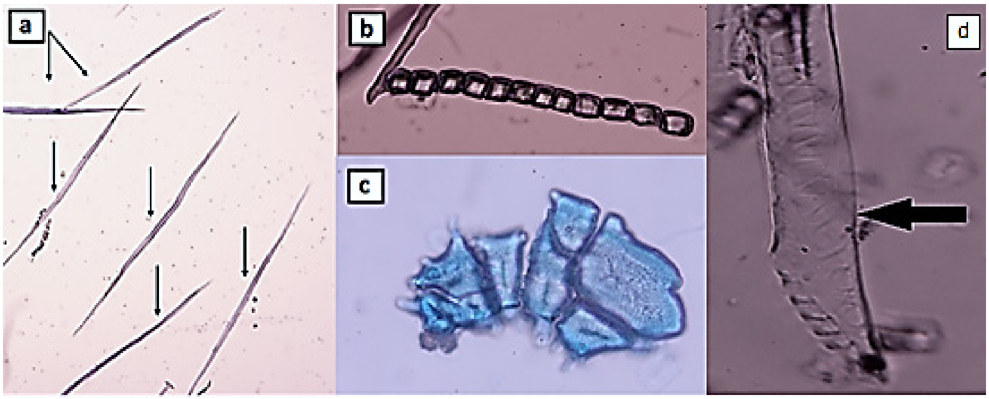

Fig. 8 The basic elements the cellular structure constituted of phloem in oak bark – phloem fibres (a), parenchyma (b), sclereids (c) and sieve cell (d).

Statistical evaluation we focused on the final evaluation of the results. Method of analysis of variance (ANOVA) was elected for statistical evaluation of measured results.

The method based on the tested criteria ($p < 0.05$) looked into addiction and the interval variable (shear strength) nominal variables (month). The evaluation test in both directions were used fresh (Fig. 9, 10) and dry condition (Fig. 11, 12).

Months	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}	{11}
	0,70	0,64	0,80	0,63	0,62	0,54	0,56	0,62	0,44	0,37	0,41
Júl		0,29	0,08	0,26	0,19	0,01	0,03	0,19	0,00	0,00	0,00
August	0,29		0,01	0,89	0,72	0,13	0,22	0,71	0,00	0,00	0,00
September	0,08	0,01		0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Október	0,26	0,89	0,01		0,81	0,15	0,26	0,80	0,00	0,00	0,00
November	0,19	0,72	0,00	0,81		0,21	0,35	0,97	0,00	0,00	0,00
December	0,01	0,13	0,00	0,15	0,21		0,71	0,21	0,08	0,00	0,03
Január	0,03	0,22	0,00	0,26	0,35	0,71		0,33	0,04	0,00	0,01
Február	0,19	0,71	0,00	0,80	0,97	0,21	0,33		0,00	0,00	0,00
Marec	0,00	0,00	0,00	0,00	0,00	0,08	0,04	0,00		0,22	0,58
Apríl	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,22		0,45
Máj	0,00	0,00	0,00	0,00	0,00	0,03	0,01	0,00	0,58	0,45	

Fig. 9 The dependence of shear strength for months of testing evaluated Duncan test the longitudinal direction of the fresh state

Months	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}	{11}
	0,27	0,33	0,39	0,36	0,39	0,37	0,36	0,39	0,30	0,22	0,22
Júl		0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,18	0,03	0,03
August	0,02		0,01	0,12	0,01	0,10	0,18	0,01	0,27	0,00	0,00
September	0,00	0,01		0,25	0,97	0,29	0,16	0,91	0,00	0,00	0,00
Október	0,00	0,12	0,25		0,24	0,87	0,75	0,22	0,01	0,00	0,00
November	0,00	0,01	0,97	0,24		0,28	0,16	0,89	0,00	0,00	0,00
December	0,00	0,10	0,29	0,87	0,28		0,65	0,27	0,01	0,00	0,00
Január	0,00	0,18	0,16	0,75	0,16	0,65		0,14	0,02	0,00	0,00
Február	0,00	0,01	0,91	0,22	0,89	0,27	0,14		0,00	0,00	0,00
Marec	0,18	0,27	0,00	0,01	0,00	0,01	0,02	0,00		0,00	0,00
Apríl	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,97
Máj	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,97	

Fig. 10 The dependence of shear strength for months of testing evaluated Duncan test the tangential direction of the fresh state

The statistical method by ANOVA showed that, in both cases fresh and dry state have significant differences. Subsequently, was evaluated importance on the basis of the tests of contrasts by the Duncan test. The significant differences in shear strength were in selected months. In view of the fresh state is a statistically significant difference in the longitudinal direction at a shear strength determined September to March, April and May. A similar result was found in the tangential direction of fresh state, which is considered important months of July, March, April and May.

Months	{1}	{2}	{3}	{4}	{5}
	0,99	1,24	1,33	1,35	1,26
Júl		0,00	0,00	0,00	0,00
August	0,00		0,32	0,24	0,81
September	0,00	0,32		0,81	0,41
Október	0,00	0,24	0,81		0,32
November	0,00	0,81	0,41	0,32	

Fig. 11 The dependence of shear strength for months of testing evaluated Duncan test the longitudinal direction of the dry state

Months	{1}	{2}	{3}	{4}	{5}
	1,43	1,49	1,61	2,11	1,92
Júl		0,70	0,27	0,00	0,00
August	0,70		0,42	0,00	0,01
September	0,27	0,42		0,00	0,03
Október	0,00	0,00	0,00		0,18
November	0,00	0,01	0,03	0,18	

Fig. 12 The dependence of shear strength for months of testing evaluated Duncan test the tangential direction of the dry state

On the basis of Duncan's test was evaluated dry state (Fig.). In the dry state was statistically significant on the month of July in the longitudinal direction and vice versa in the tangential direction, the months of October and November shows differences in the fresh and dry state, especially in September, March, April and May can be attributed to the crossing month from the growing to the dormant period and vice versa.

CONCLUSION

- The values of shear strength are better in fresh tangential samples. Our observations give findings that, the tangential plane is best for debarking process.
- Longitudinal direction shows higher values of shear strength. Therefore, in longitudinal direction is protective function of bark is most effective.
- A significant factor for debarking process is moisture content too. The fresh samples have shear strength 300 up to 350 % higher than the dry samples.
- Shear strength is higher of fresh sample in longitudinal direction 90 % than in tangential samples. Dry samples of longitudinal direction increased of the 50 % with compare tangential samples.
- From the perspective of debarking process are more effective period (July, August, March, April, May)
- The results demonstrated a significant effect of wood and bark moisture which the resulting value of shear strength affected.
- Mechanical functions by microscopic observations are thick phloem fibres and sclereids in phloem zone.
- Cambial zone has significant influence on the final results of shear strength between growing and dormant period, which is probably caused by different quality and quantity of cambial cells. These changes are confirmed by the actual statistical evaluation. The month September, March, April and May are crossing months which demonstrated statistically significant values of sear strength.

ACKNOWLEDGEMENTS
The authors are grateful for the support of the Internal Project Agency (IPA) No. 5/2016.

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