RESEARCH ON THE HARDNESS AND METALLOGRAPHIC STRUCTURE OF STEEL FOR THE FURROW OPENERS FROM CEREAL SEEDERS

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The furrow openers of agricultural seed drills are the organs that opens the furrows into which the seeds are introduced. External friction forces develop between the soil and the furrow opener, as well as other types of stresses. Lately, furrow openers with discs made of boron alloyed steel sheet have been used especially so that during the heat treatment, variable harnesses can be obtained in different areas of the disc. In general, the discs have a hardness between 48-60 HRC, lower values at the center of the disc (near the hub) and higher values on the outside, to ensure both flexibility and appropriate wear resistance, higher by 30-35% in no-till conditions. The paper presents a metallographic study of the steel of the furrow opener with discs of agricultural seed drills, as well as an analysis of the hardness of the discs in the radial direction. The objective of the paper is to present possible differences between the metallographic structure and the hardness of the material specified by the manufacturer and that which is actually found in the furrow openers with discs of the seed drills in operation. It was found, mainly, that the hardness can suffer due to the working conditions in the field, and the structural composition of the steel presents the general appearance of a structure formed by tempering sorbite. We found that the hardness of the discs is around 525-530 HB (respectively 50-52 HRC).

Keywords: hardness, metallographic analysis, agricultural seeder, coulter discs

1. Introduction

For the discs of agricultural seed drill openers, high-carbon steels or alloy steels are typically used, as they provide an optimal balance between hardness, wear resistance, and toughness.

Steels with a carbon content of approximately 0.6–1.0% are known for their high hardness after heat treatment, making them suitable for components

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subjected to abrasion, such as the discs of openers (for example, steels like 65Mn, C60, or C80).

Alloy steels used in this context contain various alloying elements (such as chromium, manganese, nickel, molybdenum) that enhance mechanical properties. For example, manganese alloy steels are known for their increased hardness and resistance to impact and wear (e.g., 42CrMo4 - chromium-molybdenum alloy steel or 30MnB5 - manganese-boron alloy steel).

Stamping from boron-alloyed steel sheet is preferred for manufacturing, as it allows for achieving variable hardness in different areas of the disc during heat treatment. The diameter of the discs ranges from 340 to 420 mm, and their thickness is between 3.5 and 4.5 mm.

However, the addition of boron to the steel composition reduces the migration of carbon through the martensitic phase as the boron content increases.

Results obtained by Ghali S.N. et al. [1], showed that adding boron up to 0.0023% can enhance the steel's properties at the lowest tempering temperatures and times. They also demonstrated that to improve the effectiveness of boron in increasing steel hardness, it is necessary to add titanium, which has a higher affinity for nitrogen than boron.

Additionally, for soil-processing tools, which are subject to wear, coatings can be applied using Eutalloy 10112 (CrNi-based alloy powder containing 60% hard particles - Diamax) to enhance resistance to corrosion and abrasion [2]. It is well known that coatings can also be applied using other types of materials, with the ultimate goal being to increase the wear resistance of soil-processing tools, [3].

The steels used also for the tools of agricultural machines that process the soil or make trenches for the introduction of seeds, such as AISI 1010 and AISI C1064, show a wear rate of more than 50% higher for AISI 1010 than for AISI C1064, regardless of the operating conditions and soil characteristics [4].

In specialized works, soil is generally theoretically modeled as an elastic-viscous medium, while the working bodies of agricultural machinery are considered as absolutely solid/rigid bodies, but the results obtained are influenced by the geometrical parameters of the working bodies, the type of its movements and the physical-mechanical properties of the soil [5].

Disc coulter openers for inserting seed into the soil usually have less depth fluctuation and soil disturbance compared to other types of openers, although when sowing in stubble conditions, they have problems when there is plant debris on the soil surface [6]. This is why they prefer other types of coulter bar on seeding machines.

The row unit of the Vaderstad seed drill, with double-disc furrow openers, is shown in figure 1. The furrow opener is shown next to it (front view, rear view and view from the machine).

Fig.1. Vaderstad seed drill section and furrow opener

The hardness of coulter discs for agricultural seed drills varies according to the material used and the heat treatments applied. Typically, these disks are made of hardened steel, and their hardness can range from 45 to 60 HRC (Rockwell Hardness C), depending on the manufacturer's specifications and the intended use of the equipment. The lower values are in the center of the disc and the higher values are on the outside to provide flexibility as well as adequate wear resistance, 30-35% higher in rough terrain conditions.

The higher hardness provides increased wear resistance, which is important to maintain efficiency in hard or abrasive terrains. However, excessive hardness can lead to brittleness, so manufacturers try to balance hardness with impact resistance [7, 8, 9].

After stamping, the discs are typically subjected to heat treatments such as hardening and tempering to achieve the desired hardness without compromising toughness. For high-carbon steels or alloy steels, these treatments can increase hardness to 45-60 HRC while maintaining good impact resistance. These properties are essential for furrow discs, which must penetrate hard soil and withstand continuous abrasion.

During the heat treatment, higher temperatures are applied to the outer edge of the disc to induce structural changes in the carbon structure of the steel.

Fig. 2. Zones of Different Hardnesses of Seed Drill Furrow Discs

https://wearpartsweb.com; https://sidist.com

Naturally, the middle area of the disc also heats up during heat treatment, but the temperature reached is lower. This area is highlighted in the figure by the orange color and is harder than untreated steel, but still retains a degree of flexibility (50-55 HRC).

The central zone (near the hub), highlighted in green, does not reach sufficiently high temperatures during the treatment, so no structural changes occur in the carbon, and this area remains in its natural, flexible state (49-50 HRC). This is important because, while the cutting edge is subject to wear due to soil contact, the center of the disc experiences greater stresses from the weight of the machinery and soil resistance, making the area closest to the hub more prone to breakage. Therefore, maintaining flexibility in the central area of the disc reduces this risk. Hence, green provides flexibility, yellow ensures durability, and red provides hardness against abrasive and hard soil particles, [10].

The hardness of notched discs compared to straight discs does not differ significantly in terms of the material or heat treatments applied, as both types of discs are usually made from the same types of steels.

Notched discs have wavy or serrated edges, which give them a better ability to penetrate compacted soil and cut plant debris. They are preferred in heavy soil conditions or where there is a lot of plant debris, as the serrated edge improves the cutting and soil mixing ability.

Straight discs have smooth edges and are commonly used for lighter soils where the same penetrating or cutting force is not required to cut through plant debris. They provide a more uniform cut and are easier to pull through the soil, requiring less tractive power.

However, disc openers from various manufacturers (for example, Väderstad, John Deere, case-IH et al.) differ in several aspects, such as design, materials used, manufacturing technology and the way they are designed to adapt to different soil conditions and farmer requirements.

For example, Väderstad coulter disks are known for their innovative design, often having a slightly conical shape, which allows them to penetrate the soil more effectively and create a well-defined seedbed. Väderstad often uses double 'V' shaped disks for a more uniform seeding.

At the same time, John Deere coulter discs tend to be more traditional in design, but are very effective in a variety of soil conditions. They can have smooth or serrated edges, depending on the model and the specifications for which they are designed. John Deere places great emphasis on versatility and adaptability to different soil types and seeding conditions.

While each brand offers high-quality products, the choice between disc openers from one manufacturer or another depends on the specific needs of each farmer, the type of soil to be worked, and personal preferences regarding technology and reliability.

Regarding the microstructure and surface properties of OL45 furrow discs, laser treatments depend on the parameters used to achieve suitable hardness and wear resistance for field work. For laser powers of 400-600 W, the hardened layer provides a hardness of up to 58-61 HRC and excellent wear resistance, [11].

It has also been demonstrated that by applying surface treatments to the discs, it is possible to alter the microstructure of this layer, thereby increasing hardness and wear resistance, [12]. Thus, the authors demonstrated that laser treatments increase hardness by 2.5 times compared to untreated discs, and by approximately 3 times compared to thermal spraying. Additionally, wear on the disc after laser treatment was 5 times lower than that of the untreated disc, and 6 times lower after thermal spraying. However, considering the extent of the modified areas, laser alloying could be a more effective treatment than thermal spraying, [12].

This study presents certain aspects of research regarding the hardness of Vaderstad seed drill furrow discs, both under severe wear conditions resulting from field work and for new discs. Measurements were carried out at multiple points on the surface of the discs, both radially and along four radial directions spaced 90° apart. Hardness was determined from the outer edge of the disc towards the center to estimate the radial hardness gradient. Additionally, metallographic structure analyses of the discs were conducted to compare with results from other global researchers.

2. Materials and methods

Hardness tests on the disc plates were conducted using a portable GE KrautKramer MIC-20 hardness tester in the *ecomet.pub.ro* laboratory of UNSTPB, using Vickers hardness units. The MIC 20 is a dual-function device that allows measurement by both ultrasonic and impact methods, in any of the standard units (directly or converted according to DIN 50150 or ASTM E140): HV, HB, HRB, HRC, HL, HSD, and N/mm². The tests were conducted in December 2024, at laboratory temperature and humidity (approx. 25ºC, 45% RH).

Four (4) used discs from Vaderstad seed drills were selected for testing, with a diameter of ϕ380 mm and a plate thickness of 3.8 mm, which had already been in operation (two notched and two plain discs, two with hub and two without hub) and one new disk were chosen from Vaderstad seed drills in production to be subjected to hardness testing. As shown in figures 3 and 4, the discs were cleaned and polished in the areas where measurements were taken, and markings were made on the discs along four radial directions, spaced approximately 20-22 mm apart. Solvent cleaning and grinding were performed superficially, carefully, at ambient temperature, so as not to affect the results of subsequent determinations. Measurements were performed on five relatively concentric circles at approximately ϕ340 mm, ϕ295 mm, ϕ250 mm, ϕ205 mm and ϕ170 mm, to observe any potential non-uniformities in different areas of the discs.

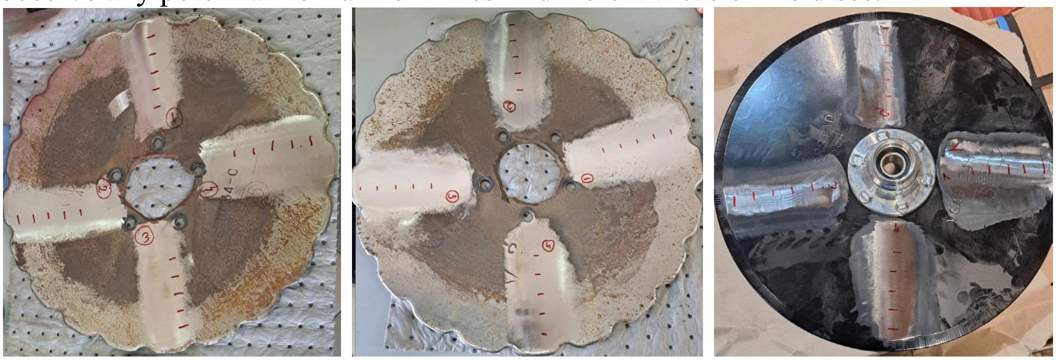

Fig. 3. Appearance Vaderstad discs marked for hardness testing

The tests were conducted using the Vickers scale, and conversion to Rockwell units was carried out using the chart shown Fig.5. In addition to the tests on the hardness of the seed drill furrow discs, the metallographic structure of these discs was determined in order to estimate the chemical composition of the steel used in their manufacture.

Metallographic analysis was performed on an Olympus BX51M Optical Microscope, for bright / dark / polarized light field investigations, with image acquisition and analysis software with applications in metallurgy.

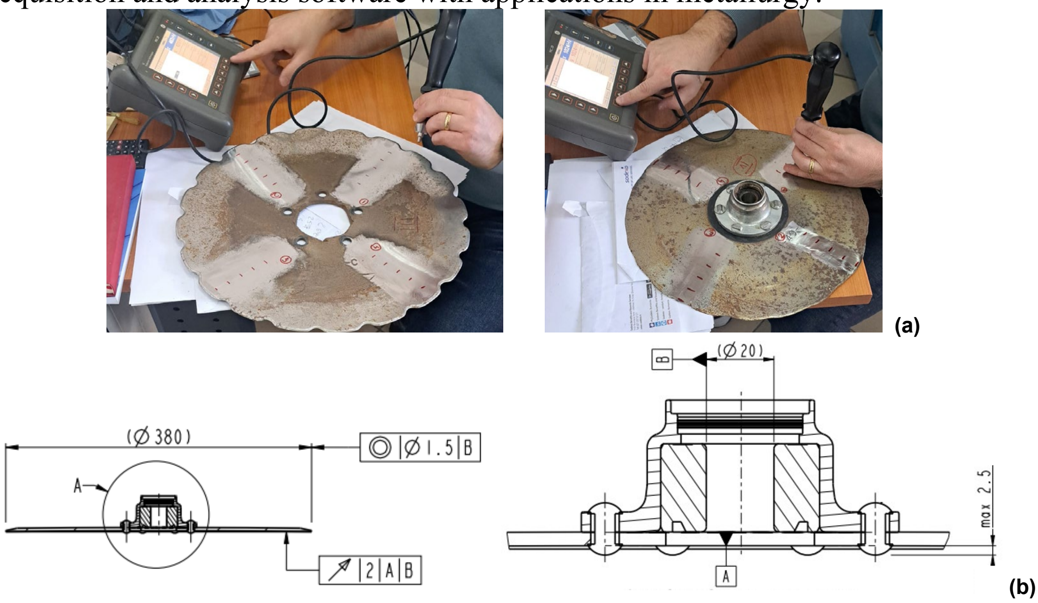

Fig. 4. Hardness testing with the portable hardness tester and discs dimensions
a) aspects from the hardness measurements b) overview drawing of the furrow disc

The microscopy images, both in transversal and longitudinal section, reveal a high physical purity of the material with a low density of inclusions.

There are hower some blue-gray rounded particulates in transversal section, with corresponding elongated blue-gray elongated particles in longitudinal section.

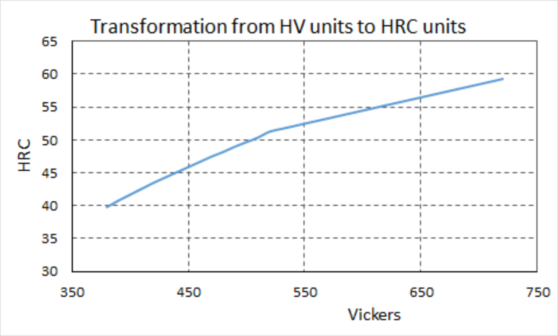

Fig. 5. Conversion of HV hardness units to HRC units

According to their morphology and shade, they belong to the Mn (and/or Fe) sulphides Mn(Fe)S. They have a very low length and density, suggesting that the sulphur impurities are at the lower limit of the chemical composition.

For each disc, both in radial and concentric directions at different distances from the center of the disc, based on the results obtained, one-way ANOVA analysis (one-way analysis of variance) was performed in Microsoft Excel Version 2406 in order to identify significant differences (LSD) between the groups of values obtained.

The one-way ANOVA (one-way analysis of variance) test is a statistical technique used to determine whether there are significant differences between the means of three or more independent groups. This test evaluates between-group and within-group variability to determine whether the variances between group means are greater than would be due to chance.

The one-factor ANOVA test was used to compare the means of the four groups of hardness values from the four used disc and the new, unused in-service disc to determine if there were significant differences between them.

The assumptions made to ensure the validity of the results were:

- null hypothesis (H_0): there are no significant differences between the group means (all means are equal).
- alternative hypothesis (H_1): There is at least one significant difference between the group means.

The ANOVA test determines an F statistic value, which represents the ratio of the mean variability between the data groups to the mean variability within the groups. A high *F* value suggests significant differences between the groups. In addition, a *p* value is determined, which represents the probability that the observed differences occurred by chance. If the *p* value is less than a specified significance level (usually 0.05), the null hypothesis is rejected, indicating significant differences between groups.

3. Results

Table 1 presents the measured hardness values at the points on the surface of the Väderstad seed drill furrow discs where measurements were taken.

It can be observed that there are relatively large differences between very close points, as seen with Disc 1 on one radial direction, with values of 429, 401, and 422 HV (where the value of 401 HV stands out from the others), or with Disc 4 on a radial direction between close points, with values of 528, 543, and 505 HV (where the value of 505 HV is notable).

Similarly, variations are apparent on concentric directions (at the same distance from the center of the disc), as seen with the new disc with values of 470, 435, 472, and 481 HV (where the value of 435 HV is quite different from the others) or with Disc 1, where the value of 401 HV stands out compared to the other radial directions (401, 472, 435, 439 HV). This is why we decided to apply the one-way ANOVA method to test the variance among value groups (either radial or concentric directions).

The graph of the average hardness values of the furrow discs, for the five concentric circles where measurements were taken, is shown in Fig.5.

Table 1

Measured hardness values of Väderstad seed drill furrow discs

Disc No.	Disc condition	Hardness in measuring points (HV)				
		Point 1	Point 2	Point 3	Point 4	Point 5
1	worn, with a hub	421	429	401	422	419
		440	451	472	451	431
		439	433	435	467	428
		422	460	439	433	434
2	worn, without a hub	457	452	429	432	460
		445	461	462	469	475
		461	486	488	461	493
		431	465	483	458	474
3	worn, without a hub	484	463	447	483	495
		466	495	463	488	480
		466	454	463	479	441
		468	464	458	473	454
4	worn, with a hub	507	506	528	543	505
		502	461	512	454	494
		497	518	480	506	490
		489	473	499	491	481
5	new, with a hub	464	470	450	461	458
		441	435	471	448	542
		451	472	435	444	449
		477	481	467	440	492

It can be observed that there is no uniformity of these values, neither from one disc to another at the same measurement point, nor among the five measurement points on the same disc, even though all values fall within the range prescribed by the manufacturer. Thus, all hardness values are above 420 HV (approximately 44 HRC) but below 500 HV (approximately 50 HRC), as recommended for such discs (45-60 HRC).

As previously mentioned, it was observed that even for all four radial directions where measurements were taken at the same distance from the center of the disc, the hardness values did not exhibit uniformity. This leads us to conclude that either the material experienced changes during the working process or the initial treatment was not conducted properly, although the values are above the minimum recommended.

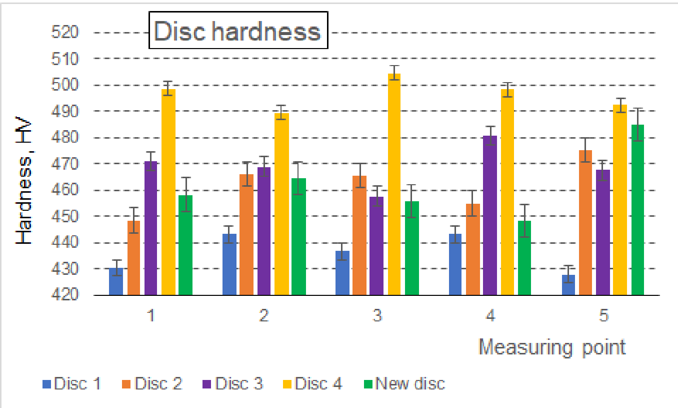

Fig. 5. Graph of the average hardness values measured on the 5 discs, across concentric circles

However, it can be noted that there are discs with a higher average hardness value (such as Disc 4, with an average hardness of over 490 HV), or discs with a lower hardness value (such as the used Disc 1, with an average hardness of approximately 435 HV).

The one-way ANOVA test, with the summarized values presented in Table 2, also indicates a variance of values with *F* values greater than the *critical F* value, as observed for Disc 1 for concentric directions (F=4.295 > F *critic*=3.239), or for Disc 2 for radial directions (F=3.474 > F *critic*=3.239). In other cases, the F values relative to the critical F value do not present significant issues, for both radial and concentric directions.

Regarding the *p* value, which indicates the probability of obtaining an *F* statistic value as observed given that the null hypothesis is true, it is noted that only for Disc 1 (for the five concentric directions) and Disc 2 (for the four radial directions) is the p-value lower than the significance level of 0.05. This suggests evidence against the null hypothesis, indicating that there is a significant difference between the means of at least two groups (for these two discs, though it does not specify which groups are contributing to this phenomenon).

For the other discs, both for radial and concentric direction groups, the p-value is greater than 0.05, meaning the null hypothesis cannot be rejected.

This implies there is insufficient evidence to support the claim of significant differences between the group means. Practically, any observed differences could be due to chance.

The *p* value therefore needs to be small (below the established significance level) to indicate a significant difference between groups, which is not the case.

Table 2

Centralized values determined from the ANOVA test for *F, p* şi *F critic*

	For radial directions			*For concentric circles*		
	F	*P-value*	*F crit*	*F*	*P-value*	*F crit*
Disc 1	0.622	0.654	3.055	4.295	0.021	3.239
Disc 2	3.474	0.041	3.239	1.426	0.273	3.055
Disc 3	1.791	0.189	3.2389	1.238	0.337	3.055
Disc 4	3.066	0.069	3.490	0.248	0.861	3.490
Disc 5 (new)	0.673	0.581	3.239	1.418	0.277	3.055

Upon further analysis of the *F* statistic values (relative to the *critical F* value) and *p* values for the groups of values determined from the four used and worn discs, the data presented in Table 3 are obtained.

Table 3

Values of the parameters *F, p* and *F critic* from the ANOVA test for worn discs

- for radial direction

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9265.809375	3	3088.603	46.91363	$3.75 \cdot 10^{-08}$	3.238872
Within Groups	1053.375	16	65.83594			
Total	10319.18438	19				

- for concentric direction

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	107.1687	4	26.79219	0.039354	0.996714	3.055568
Within Groups	10212.02	15	680.801			
Total	10319.18	19				

It can be concluded that for radial directions, both the *F* value and the *p* value indicate significant differences between the means of the value groups for the used and worn discs. In contrast, for concentric directions, these values indicate that there are no significant differences.

The same conclusion applies when analyzing the hardness test results overall for the discs tested (including both the used discs and the new disc), as shown in Table 4.

Table 4

Values of the parameters *F, p* and *F critic* from the ANOVA test for worn discs

- for radial direction

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9320.94	4	2330.235	25.30698	$1.4 \cdot 10^{-07}$	2.866081
Within Groups	1841.575	20	92.07875			
Total	11162.515	24				

- for concentric direction

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	188.865	4	47.21625	0.086054	0.985775	2.866081
Within Groups	10973.65	20	548.6825			
Total	11162.52	24				

The optical microscopy studies on the attacked samples were performed at low magnifications (M=200x) for an overview of the structure, but also at higher magnifications (M=500x) to highlight certain structural details of interest. The general appearance corresponds to a structure consisting of tempered sorbite, which resulted from the mixed thermal treatment of martensitic quencing and high tempering, i.e., improvement. The state of inclusion is very low, proving processing that complies with the specific norms. It was found, however, that the measured average hardness has values above the limit of one sorbite (52 HRC), which could be explained mainly by the precipitation hardening mechanism, very intense.

4. Conclusions

From the analysis of the data presented and described throughout the paper, it can be concluded that the hardness values of the Vaderstad planter discs generally align with the recommendations and technical specifications provided by the manufacturers of such tools. However, it cannot be asserted that this value varies consistently along the radial direction, being higher at the edge of the disc and lower towards the center, as the determined values exhibit non-uniformities both along these directions and on concentric circles (at the same distance from the center of the disk). Thus, either the material has undergone changes during the operation of the planters, or the initial heat treatment was not conducted according to the recommended specifications. However, the values obtained for the hardness of the material fall within the limits prescribed by the manufacturer (50-60 HRC).

Based on the hardness values obtained and the results of the one-way ANOVA tests, it can be concluded that for radial directions, both the *F* statistic parameter and the *p* value indicate significant differences between the means of the value groups for both the used and worn discs and overall (for the analyzed discs). In contrast, for concentric directions, these values suggest that there are no significant differences.

The experimental data presented by the authors may lead manufacturers to find additional solutions to increase wear resistance. The authors propose, for example, coating the discs with epoxy resin up to about 15 mm from the edge of the disc for better sliding in the soil layer and greater wear resistance.

Acknowledgement

This work has been funded from the project "Improving the base of practical applications for bio-technical systems in solariums, gardens, vineyards and orchards (APSISBIO)" CNFIS-FDI-2024-F-0112, from the Ministry of Education through the Executive Agency for Financing Higher Education, Research, Development and Innovation.

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