BICYCLE HANDLEBAR DESIGN WITH HIGH DAMPING FACTOR USING NATURAL COMPOSITES

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ABSTRACT:

This study considers the design and development of a sport good with structural and vibration damping requirements, such as a bicycle handlebar. The methodology developed and the gained experience can later be applied to other types of sport goods. The study begins with the selection and subsequent characterisation of sustainable material systems, as well as their comparison with other conventional materials. For this purpose, the mechanical properties and the damping factor of the material were analysed in both flat and tubular samples, taking into account the orientation of the reinforcement fibers. The experimental results are used in the development of the handlebar, simulating by means of finite elements the structural behaviour under the load cases established in the standard, and the vibrational response. Once this behaviour has been optimised, prototypes are manufactured using both composite materials with natural reinforcements, in this case flax, and carbon fiber reinforcements. The prototypes are tested to validate and compare the behaviour at component level and the necessary improvements are proposed in order to comply with all the specifications that this type of product must meet.

Keywords: Natural composites; sustainability; vibration damping; cycling.

1.- INTRODUCTION

In the field of sports, the use of natural composites, such as hemp, flax and sisal, is practically non-existent. In addition to the well-known advantages provide by composites, such as lightweight, high specific strength and stiffness, and free-corrosion [1-4], these natural composites have better vibration damping than glass or carbon composites [4-6], which is very important in most sporting activities. Unlike carbon fiber composites, natural fiber composites have a ductile fracture behaviour without sharp fibers, which improves safety compared to carbon fiber composites with brittle fractures with sharp fibers and emission of toxic carbon fiber dust, which is an advantage in terms of safety [7-9]. However, their mechanical properties are lower than glass or carbon fiber reinforced composites. Society's awareness of environmental issues is growing every day, especially among the practitioners of many of these sporting disciplines that are enjoyed in a natural environment [10]. However, although the future of these materials looks promising, it seems difficult to believe that any user would be willing to sacrifice technical performance or safety for a more sustainable product, especially among professional sportmen and women, who are often the sales benchmark for this type of equipment. Therefore, a number of uncertainties need to be overcome before natural composites can be introduced into the design of sports equipment. Overcoming these uncertainties requires an in-depth knowledge of these material systems, in which the mechanical properties and behaviour are highly dependent on the manufacturing processes [4]. This knowledge can be achieved through the complete characterisation of the material, especially in many aspects of its behaviour in which there is not yet adequate information to be able to design components with high structural requirements.

In this study, the design and development of a sports component with structural and vibration absorption requirements, such as a bicycle handlebar, is considered. The methodology developed and the experience acquired can later be applied to other types of sports products. The study begins with the selection and subsequent characterisation of sustainable material systems, as well as their comparison with other conventional materials. For this purpose, the mechanical properties and the damping factor of the material were analysed, taking into account the orientation of the reinforcement fibers.

The experimental results are used in the development of the handlebar, simulating by means of finite elements the structural behaviour under the load cases established in the standard [11], and the vibrational response. Once this behaviour has been optimised, prototypes are manufactured using both composite materials with natural reinforcements, in this case flax, and carbon fiber reinforcements. The prototypes are tested to validate the behaviour at component level and the necessary improvements are proposed to comply with all the specifications that must be met by this type of product.

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2.- MATERIALS BEHAVIOUR

As introduced earlier, natural fibers offer very good performance in terms of vibration damping; nevertheless, their mechanical behaviour is more limited compared to carbon fibers. Therefore, flax fiber was selected for this work, since, apart from its commercial availability, it is the most stiff and strength of the natural fibers. Besides, in order to obtain a higher sustainability of the final product a bio-based epoxy resin (Greenpoxy 33/ SD 4772 - Sicomin) was used as matrix system, which provides good mechanical performance and excellent compatibility with these fibres. In addition, carbon fiber reinforced impregnated with the same resin and aluminium 6061 samples were analysed as counterpart.

2.1.- NUMERICAL ANALYSIS

Initially, with the SolidWorks® simulation module, finite element models were made, using shell elements, of both the flat specimens (8,620 elements) and the tubular specimens (14,580 elements) to determine the most suitable dimensions for the experimental study of the natural frequencies and the damping factor. Both tubular and plate specimens were rigidly fixed at one end, leaving the other end free, in a cantilever configuration.

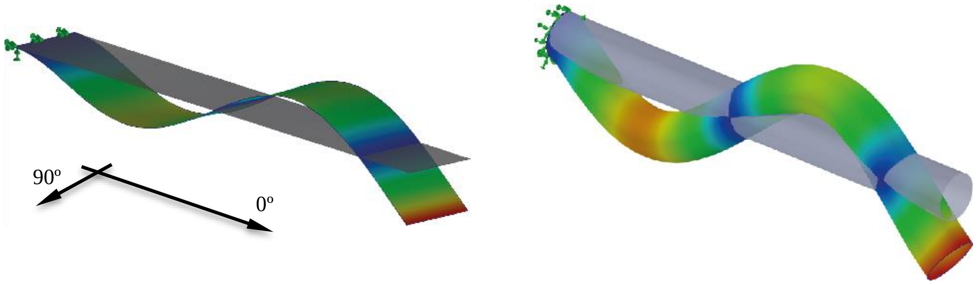

Fig. 1. FE models for flat and tubular samples.

After this previous frequency study, the optimum dimensions for the experimental test were set at 300 x 40 mm, with thicknesses about 2 mm for the flat specimens. The tubular samples were set at a length of 600 mm, a diameter of 30 mm and a thickness of 2 mm. In this way the frequencies were within the measurement range of the equipment, which will be described in the following section. Table 1 shows the first six natural frequencies for flax and carbon flat specimens with the selected dimensions. It can be observed that the natural vibration frequencies for the carbon specimens are higher for the 0° fiber orientation (fiber following longitudinal axis) in all the modes analysed. While the ±45º and 90º specimens, they are higher in the first modes, but are equated and even exceeded from the third mode onwards. This may be due to a greater influence of the matrix.

	Orientation 0º		*Orientation ±45º*		*Orientation 90º*	
Mode	*Flax*	*Carbon*	*Flax*	*Carbon*	*Flax*	*Carbon*
1	12,3	27,1	16	18,6	5,3	8,4
2	76,8	169,9	100	116,1	32,9	52,7
3	215	212,4	280	216,5	92,3	143,7
4	258	394,1	550	326,8	182	178,6
5	421	474,8	908	640,9	298	288,8
6	695	656,7	1346	1059	445	476,9

Table 1. Natural frequencies (Hz) of flax and carbon plate samples.

2.2.- MANUFACTURING AND EXPERIMENTAL CHARACTERIZATION

Afterwards numerical analysis, the flat and tubular samples were manufactured. For the purpose of analysing the influence of fiber orientation in the vibrational behaviour, different specimens have been manufactured varying the fiber orientation (0º, 90º, +-45º, 0-

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90º), as well as two hybrids (flax-carbon) with fibers at 0º to observe their behaviour, 4 layers of 300 g/m^2 UD fabric are used for this purpose. In the case of tubular samples, ±60º braiding fabrics were used.

Once impregnated by hand, flat samples were compacted by vacuum bag technique applying 0.8 bar of vacuum (Fig. 2), whereas tubular samples were moulded using a cylindrical external mould and an inner inflatable blade. In addition, aluminium samples with the same dimensions were cut in order to have other traditional sporting material to benchmark.

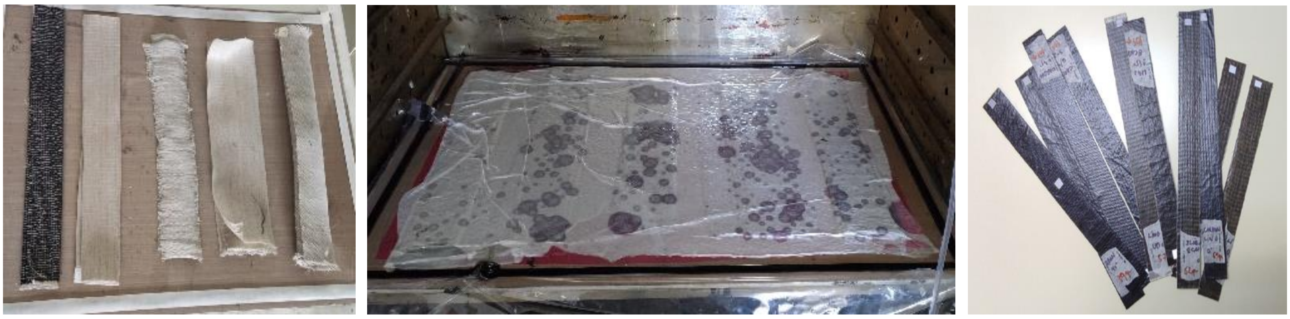

Fig. 2. Flat samples manufacturing: Dry preforms, vacuum bag compaction, cut samples.

The experimental characterization of the natural frequencies and damping of the different specimens tested was carried out using the technique of measuring the vibratory response to an impulse force. This technique adequately excites the structure within the frequency range of interest, determining the Frequency Response Function (FRF) using the Fourier transform to identify the natural frequencies and the damping associated with each one of them. The Endevco 2302-10 impact hammer was used to excite the structure and the response was measured using a Polytec PDV100 laser vibrometer, which does not add mass to the structure analysed (Fig. 3 - left). The signals were recorded and processed using PULSE 9.0 software and the Brüerl&Kjaer 3560C front-end. The FRF recorded by PULSE is analysed using Vibrant Technology's ME'Scope software, which allows the values of the natural frequencies and modal damping to be determined numerically.

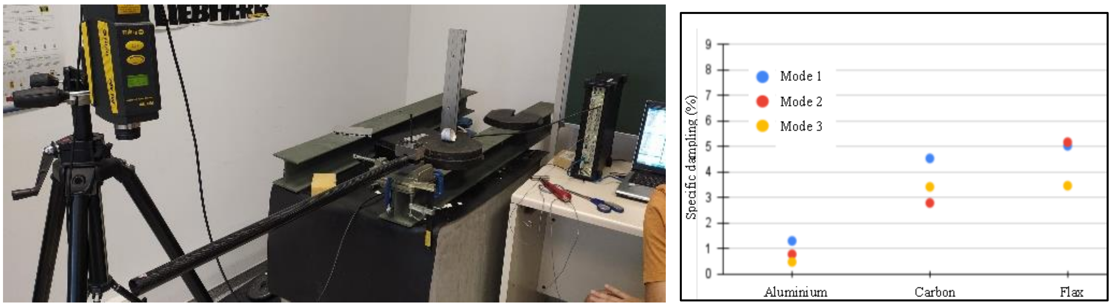

Fig. 3. Vibration test set-up (left). Tubular samples damping (right).

Fig. 3 (right) shows the experimental damping values for the first three modes in the aluminium, carbon and flax tubes. It can be seen that the aluminium tubes have the lowest damping factor, while the flax tubes have the best vibration absorption behaviour. Besides, Table 2 collects the experimental damping factors for the flax and carbon flat samples taking into account the fiber orientation.

	Orientation 0º		*Orientation ±45º*		*Orientation 90º*	
Mode	*Flax*	*Carbon*	*Flax*	*Carbon*	*Flax*	*Carbon*
1	0,57	0,12	0,78	0,326	0,97	0,32
2	0,71	0,34	0,82	0,43	0,93	0,35
3	0,6	0,92	0,89	0,49	1,01	0,48

Table 2. Damping factors of flax and carbon flat samples.

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2.3.- NUMERICAL-EXPERIMENTAL CORRELATION

In most cases, the frequencies obtained numerically follow quite well the real behaviour, at least for the first four natural frequencies (Table 3). Therefore, the proposed model is a useful tool to predict vibrational behaviour of these materials. In all the specimens tested, the flax fiber has a higher damping factor and therefore a greater capacity for vibration absorption.

The fiber orientation significantly affects both the mechanical properties and the damping factor of the material. While strength and stiffness decrease [12-15], the damping factor increases with increasing fiber angle, being minimum for 0° orientation and maximum for a fiber orientation of 90°. This is due to a higher influence of the matrix, which due to its low stiffness provides a higher damping in the transmission of vibrations. For both flat (Tabla 3) and tubular samples (Fig. 3-rigth), the flax fiber reinforced specimens show a higher damping factor than the carbon fiber and aluminium specimens.

	Orientation 0º				*Orientation ±45º*				*Orientation 90º*			
	Flax		*Carbon*		*Flax*		*Carbon*		*Flax*		*Carbon*	
Mode	*Num.*	*Exp.*	*Num.*	*Exp.*	*Num.*	*Exp.*	*Num.*	*Exp.*	*Num.*	*Exp.*	*Num.*	*Exp.*
1	12,3	12,5	27,1	27,7	16	12,1	18,6	19,3	5,3	5,16	8,4	8,3
2	76,8	78,7	170	175	100	78,4	117	121	32,9	32,2	52,7	58
3	215	83,6	475	483	280	223	327	341	92,3	90,4	147	164
4	258	222	928	938	550	440	641	690	182	183	289	309
5	421	377	1529	1550	908	736	1059	1140	298	302	477	505
6	695	401	1725	NA	1346	988	1590	NA	445	305	711	NA

Table 3. Numerical-experimental correlation of frequency data for flat samples.

3.- HANDLEBAR DEVELOPMENT

Once the different materials have been characterised and the vibrational numerical models have been correlated, the knowledge and information generated is used for the development of a handlebar application.

For this purpose, on the one hand, a mechanical test is carried out using a numerical model, obtaining a first version of the handlebar that meets these requirements. On the other hand, these first prototypes are manufactured for subsequent vibrational testing, both numerical and experimental.

3.1.- MECHANICAL BEHAVIOUR

In order to ensure the strength and durability of the handlebars, it is necessary to contemplate from the design stage the compliance of a series of mechanical tests established in the standard UNE-EN ISO 4210_5. The tests applying to the handlebar component are: lateral bending tests (tests 1 and 2) and torsional safety test (test 3).

These tests were simulated by finite element method for an aluminium reference handlebar, afterwards, a flax one was developed to provide a similar behaviour in terms of displacements. Since to obtain similar values of displacement a thicker and heavier flax handlebar is needed. Besides, a hybrid flax/carbon handlebar was developed using a thickness of 2 mm of flax braiding and 0.5 mm of unidirectional carbon (0º), in order to improve its mechanical behaviour (Table 4).

	Aluminium 6061			*Flax*			*Flax + Carbon*		
Thickness	2 mm			10 mm			2 mm + 0,5 mm		
Weight	280 g			520 g			236 g		
	Test 1	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*
Displacem..	4,32mm	3,25mm	0,018rad	5,4mm	4,1mm	0,08rad	4,3mm	3,3mm	0,1rad
Safety factor	1,34	1,61	4,63	2,08	2,47	3,56	2,36	3,34	1,83

Table 4. Mechanical behaviour of aluminium, flax and flax+carbon handlebars.

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3.2.- VIBRATIONAL RESPONSE

In order to characterise the vibration behaviour of the handlebars, the central part of the handlebars was fixed to the shaker, model 2075E from The Modal Shop, leaving a 218mm long cantilevered end. Afterwards, a random vibration of constant amplitude between 20Hz and 2500Hz was defined on the central part, which covers the frequency range in which the first three bending modes of the handlebars are found (Fig. 4 - left). The frequencies for these modes were previously estimated using a numerical model and measuring the vibration response at the free end of the handlebar (Fig. 4 - right). A PCB accelerometer T333B30 placed on the part fixed to the shaker was used to carry out the closed-loop control of the excitatory vibration and another PCB accelerometer T333B30 was used to record the vibration signal at the end of the cantilever. The test was carried out using the COMET USB control system and the LDS Dactron Shaker Control Vibration Test Random software.

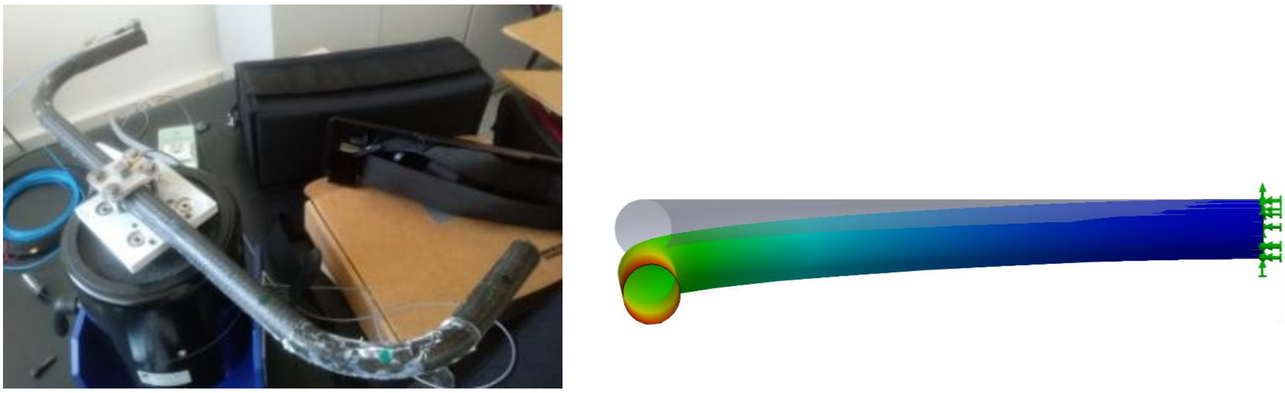

Fig. 4. Vibration test set-up: (left) shaker set-up with carbon prototype, (right) numerical model.

During the test, the transmissibility function, which relates the vibrational response to the excitation at the base, was determined, identifying the resonance peaks and the associated damping. Table 5 shows the results obtained for the two handlebars tested and compared with their numerical results. It should be noted that only the first three natural vibration frequencies associated with bending modes are considered. The aim is for these natural frequencies to be far removed from those generated by the cyclist's pedalling or by a possible electric motor [16].

	Flax Handlebar			*Carbon Handlebar*		
Mode	*Numerical Freq. (Hz)*	*Experiment Freq. (Hz)*	*Damping factor (%)*	*Numerical Freq. (Hz)*	*Experiment Freq. (Hz)*	*Damping factor (%)*
1	60.9	65	8,54	91.3	85,4	6,18
2	206.5	225	2,22	294.2	325	1,72
3	688.9	795	2,47	1023	950	1,07

Table 5. Numerical and experimental frequencies and specific damping factor for flax and carbon handlebar.

From the results obtained in the test, it can be observed that there is a good correlation between the natural frequencies obtained from the numerical model of the handlebar and those obtained from the experimental analysis, with maximum differences of around 10%. Regarding, the natural frequencies in the flax handlebar are lower than those obtained in the hybrid handlebar, due to a greater mass, 520 g versus 236 g, since the stiffness values obtained are similar in both, as shown in Table 4. Finally, the damping obtained in the flax handlebar presents higher damping values than in the case of the hybrid handlebar, due to the greater amount of flax, which presents greater damping than carbon fiber. Increased damping provides better riding performance and improved rider comfort, preventing numbness, stiffness and pain in the hands, shoulders and neck [16-18].

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4.- CONCLUSIONS

This work provides useful information on the vibration behaviour of flax fiber specimens, as well as other materials used in sporting goods. Flax fiber composites provide superior damping to the rest of the materials studied, however, in applications such as handlebars, it will be necessary to hybridise the reinforcement material with carbon fibers to achieve solutions where the strength/weight ratio is not compromised.

In this case, a hybrid handlebar material is obtained which, while meeting with all the mechanical requirements established in the standard, provides a solution 16% lighter than the equivalent in aluminium, with significantly superior damping.

From the point of view of the sustainability, this kind of biocomposites products helps to reduce the amount of solid waste with and energy consumption, they serve as an environmental friendly alternative to materials currently in use.

The working methodology and knowledge acquired in this project can be implemented in any design process applicable to other applications in different sectors.

REFERENCES

[1] Lucintel, August 2022. Composite Materials in the Sporting Goods Market Report: Trends, Forecast and Competitive Analysis.
[2] Composites World. 2023. https://www.compositesworld.com/articles/composites-end-markets-sports-and-recreation-2023 (accessed on 27/01/2023).
[3] La Rosa, A.D., Recca, G., Summerscales, J., et al. Bio-based versus traditional polymer composites. A life cycle assessment perspective. Journal of Cleaner Production. 2014. Volume 74, Pages 135-144, https://doi.org/10.1016/j.jclepro.2014.03.017
[4] Rahman M.Z., Mechanical and damping performances of flax fibre composites – A review. 2021. Composites Part C: Open Access. Volume 4. https://doi.org/10.1016/j.jcomc.2020.100081
[5] Shah, D.U.; Developing plant fibre composites for structural applications by optimising composite parameters: a critical review. Journal of Material Science. 2013. 48 (18). P 6083-6107. https://doi.org/10.1007/s10853-013-7458-7
[6] Mahmoudia, S., Kervoelena, A., et al. Experimental and numerical investigation of the damping of flax–epoxy composite plates. Composite Structures. 2019, Volume 208, Pages 426-433. https://doi.org/10.1016/j.compstruct.2018.10.030
[7] Pozo Morales, A.R. Materiales Compuestos de Fibras Naturales. Tesis (Doctoral), E.T.S. de Ingeniería Aeronáutica y del Espacio (UPM). 2019. https://doi.org/10.20868/UPM.thesis.55053
[8] Duflou, J.D.; Yelin. D.; et al. Comparative impact assessment for flax fibre versus conventional glass fibre reinforced composites: Are biobased reinforcement materials the way to go?. CIRP Annals—Manufacturing technology. 2014. Volumen 63, pp. 45-48. https://doi.org/10.1016/j.cirp.2014.03.061
[9] Pil, L.; Bensadoun, F.; Pariset, J.; Verpoest, I. Why are designers fascinated by flax and hemp fibre composites?. Composites Part A: Applied Science and Manufacturing. Volume 83, April 2016, Pages 193-205. https://doi.org/10.1016/j.compositesa.2015.11.004
[10] Borrás, C., 2017. La práctica de deportes ecológicos. https://www.ecologiaverde.com/la-practica-de-deportes-ecologicos-612.html (accessed on 27/01/2023).
[11] UNE-EN ISO 4210_5:2014. Requisitos de seguridad para bicicletas. Parte 5: Métodos de ensayo de la dirección.
[12] Poniecka, A.; Barburski, M.; Ranz, D.; Cuartero, J.; Miralbes, R. Comparison of mechanical properties of composites reinforced with technical embroidery, ud and woven fabric made of flax fibers. Materials 2022, 15, 7469. https://doi.org/10.3390/ma15217469
[13] Moudood A., Rahman A., Ochsner A., Islam M., Francucci G., Flax fiber and its composites: An overview of water and moisture absorption impact on their performance, Journal of Reinforced Plastics and Composites 2019, vol. 38, no 7, pp. 323–339. http://dx.doi.org/10.1177/0731684418818893
[14] Poniecka, A.; Barburski, M.; Ranz, D.; Cuartero, J.; Comparison of composites containing technical embroidery and woven fabric as reinforcement. 21st World Textile Conference AUTEX. June 2022. https://doi.org/10.34658/9788366741751.50
[15] Mohamed, Y.S.; Abdelbary, A.; Theoretical and experimental study on the influence of fiber orientation on the tensile properties of unidirectional carbon fiber/epoxy composite. Alexandria Engineering Journal; Volume 67, 15 March 2023, Pages 693-705. https://doi.org/10.1016/j.aej.2022.12.058
[16] Viellehner, J.; Potthast, W. (2019). Road bike damping: comfort or performance related?. July 2019. 37th International Conference on Biomechanics in Sports at: Miami University, Oxford Ohio
[17] Khune, S.; Bhende, A.; Vibration analysis of motorcycle handlebar for riding comfort using tuned mass damper. Journal of Measurements in Engineering December 2020 Volume 8(6). https://doi.org/10.21595/jme.2020.21518
[18] Rajendra. T.; Barjibhe, R.B.; Design, Analysis & Fabrication of Handlebar of Motorcycle by Changing Material. International Journal of Engineering Development and Research. Volume 6, Issue 1 | ISSN: 2321-9939

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SUPPLEMENTARY MATERIAL

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