Structural and material analysis of an innovative mixer drum with a capacity of 12 m³

Analiza konstrukcyjno-materiałowa innowacyjnego bębna mieszalnika o pojemności 12 m³

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DOI: https://doi.org/10.17814/mechanik.2023.5-6.12

A structural and material analysis of individual elements of the mixing-unloading spiral and shell segments of the innovative mixer drum of the hydraulic truck concrete mixer with a capacity of 12 m³ was developed. A complex CAD design process of individual elements in terms of the developed manufacturing technology was carried out. The construction of the mixer components was verified in the 3D-CAD system and a numerical analysis of stress distribution using the finite element method (FEM) was carried out for key segments of the spiral, which directly determines the implementation of the correct and efficient concrete mixing process. The research resulted in the development of comprehensive technical documentation of the original mixer structure, including executive drawings of the components along with a description of the manufacturing technology and the choice of the initial material–steel with increased abrasion resistance. The results of the completed research process were used in the next stage of research, i.e. bench tests of the innovative design of the 12 m³ mixer drum.
KEYWORDS: mixer drum, mixing and unloading spiral, hydraulic truck concrete mixer, CAD construction, FEM analysis, technical documentation

Opracowano analizę konstrukcyjno-materiałową elementów spirali mieszająco-rozładowującej i segmentów płaszcza innowacyjnego bębna mieszalnika hydraulicznej betonomieszarki samochodowej o pojemności 12 m³. Przeprowadzono złożony proces projektowania CAD poszczególnych przedmiotowych elementów w aspekcie opracowanej technologii wytwarzania. Konstrukcję członów składowych mieszalnika poddano weryfikacji w systemie 3D-CAD oraz przeprowadzono analizę numeryczną rozkładu naprężeń metodą elementów skończonych MES dla kluczowych segmentów spirali, która bezpośrednio warunkuje realizację poprawnego i wydajnego procesu mieszania masy betonowej. Badania pozwoliły na opracowanie kompleksowej dokumentacji technicznej autorskiej konstrukcji mieszalnika, obejmującej rysunki wykonawcze elementów składowych wraz z opisem technologii wytwarzania oraz wyborem materiału wstępnego – stali o zwiększonej wytrzymałości na ścieranie. Wyniki zrealizowanego procesu badawczego zostały wykorzystane na kolejnym etapie badań, tj. w testach stanowiskowych innowacyjnej konstrukcji bębna mieszalnika o pojemności 12 m³.
SŁOWA KLUCZOWE: bęben mieszalnika, spirala mieszająco-rozładowująca, hydrauliczna betonomieszarka samochodowa, konstrukcja CAD, analiza MES, dokumentacja techniczna

Introduction

The publication is the result of a complex research process covered by the project entitled „Research and development work for the design and manufacture of an innovative mixer drum with a capacity of 12 m³" co-financed by the European Regional Development Fund. A complex process of construction of individual segments of the shell and mixer spiral was carried out in an advanced 3D-CAD system. The construction works were carried out on the basis of relevant standards for the solutions in question and the industry knowledge and many years of experience of the research team. The generated models were subjected to detailed verification in the CAD environment and analysis of stress distribution using the FEM for key segments of the mixing-unloading spiral. Structural and material analysis enabled the development of comprehensive technical documentation of an innovative mixer drum with a capacity of 12 m³, which is the basis for the production of prototypes and subjecting them to tests in a series of bench tests.

Material analysis

Preliminary studies included material analysis. A detailed overview of the materials that can be used in the production of an innovative mixer drum with a capacity of 12 m³ has been developed. In the process of this analysis, steel sheets with increased strength

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TABLE. List of materials selected for the research process – catalog data

No.	Designation	Hardness HB	Yield strength R_E [MPa]	Ultimate strength R_M [MPa]
1	HAR-DOX450	425÷475	1200	1400
2	S355MC	220*	355	490÷630
3	S420MC	150÷190	420	480÷620
4	TBL	230	430	680
5	S690QL	230÷280	690	770÷940

* In a softened state.

parameters, including primarily abrasion resistance, were taken into account. From among the eight analyzed species, five available species were selected, which can be used in the production of an innovative construction of a hydraulic concrete mixer with a capacity of 12 m³. Selected species – their basic parameters are presented in the table.

Innovative mixer drum 12 m³

The construction of the innovative drum of the hydraulic mixer of a concrete mixer with a capacity of 12 m³ includes a shell and a mixing-unloading spiral (fig. 1 and 2).

The design of individual segments of the mixing and unloading spiral and the drum shell was developed, i.e.: the bottom, intermediate cone, cylinder, auxiliary cone, rear and minor.

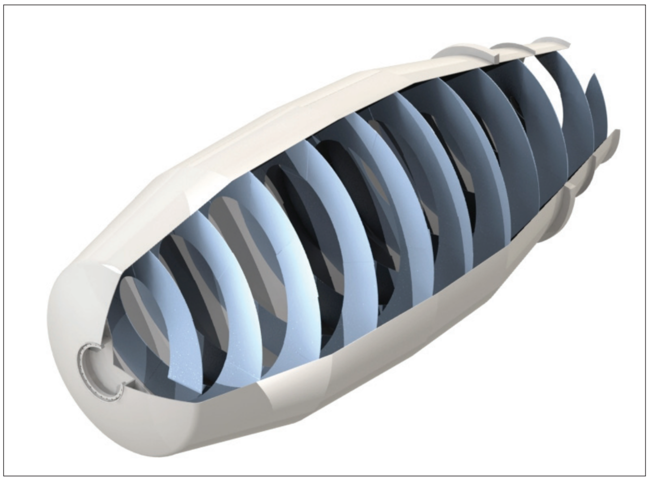

Fig. 1. Innovative mixer drum with a capacity of 12 m³

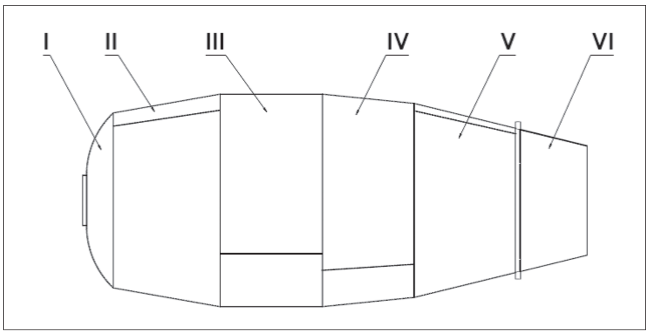

Fig. 2. Innovative mixer drum with a capacity of 12 m³ – design: *I* – mixer drum bottom, *II* – intermediate cone, *III* – cylinder, *IV* – auxiliary cone, *V* – rear cone, *VI* – minor cone

CAD – FEM analysis of the mixing-unloading spiral

In order to verify the author's design of the mixing and discharging spiral, assumptions for the analysis of stress distribution using the finite element method (FEM) were developed. Strength analyses of individual components of the mixer were performed, and in this article the results for the spiral fragment located in cylinder (*III*) are presented (fig. 8). It was assumed that the load is generated by the concrete inside the mixer. The most unfavorable variant of the load was assumed, when the entire concrete mass between the coils presses on the spiral in the normal direction. The numerical models of the spiral segments necessary

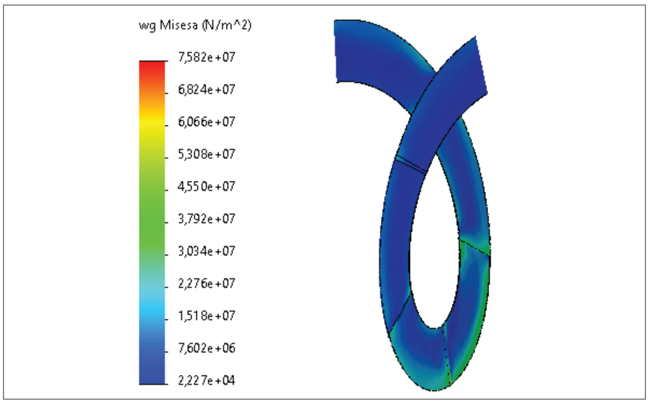

Fig. 3. Distribution of reduced stresses according to the maximum distortion criterion (Maxwell–Huber–Hencky–von Mises theory)

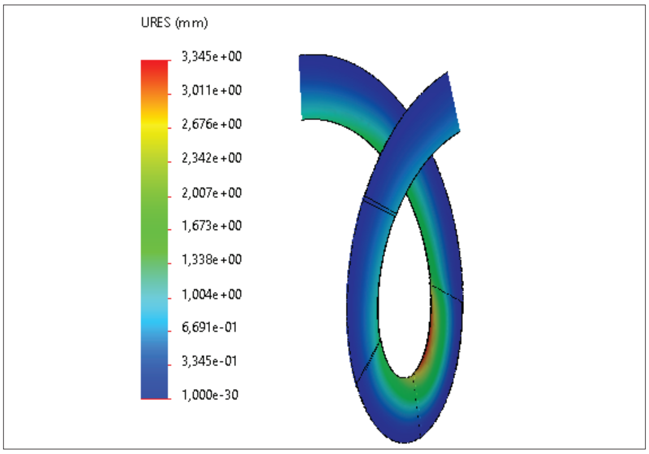

Fig. 4. Deformation distribution of a fragment of the mixing-unloading spiral

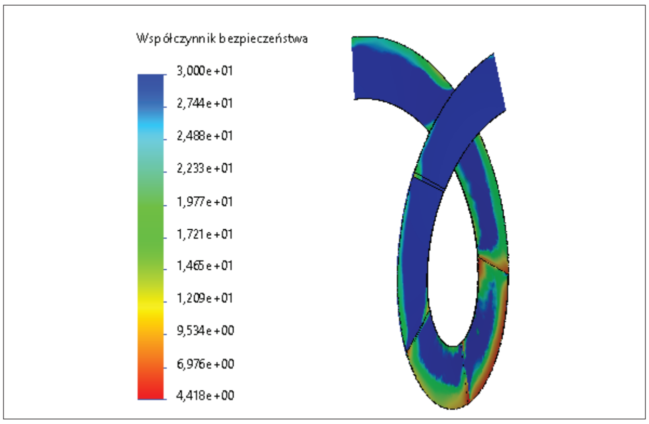

Fig. 5. Distribution of the safety factor for a fragment of the mixing-unloading spiral

for the stress distribution analysis were developed, the model was discretized and the analysis parameters were defined in the CAE system.

Selected results of FEM analysis of a section of a large mixing-unloading spiral made of S355MC steel are shown in fig. 3÷5.

The results determined by numerical analysis of the stress distribution for the examined fragment of the mixing-unloading spiral of the innovative mixer drum with a capacity of 12 m³ made of S355MC steel clearly confirm the appropriate strength of the developed spiral structure. Maximum values of reduced stress, displacement and safety factor at the appropriate levels – 75.82 MPa, 3.3 mm and 4.4 – ensure safe operation of the spiral. A safety factor of 4.4 is sufficient for this type of construction – it does not pose a risk of premature failure in the mixer operation process.

In addition, it should be noted that the FEM analysis results presented above concern the S355MC steel sheet, which has the lowest strength parameters of all three materials selected for the manufacturing process of the innovative mixer drum.

CAD design of mixer shell segments

Models of each segment are shown in the following fig. 6–13.

A model of the bottom made of 8 mm thick sheet, stiffened inside with a reinforcing cone and a hub socket, to which the planetary gear of the concrete mixer is mounted, is shown in fig. 6.

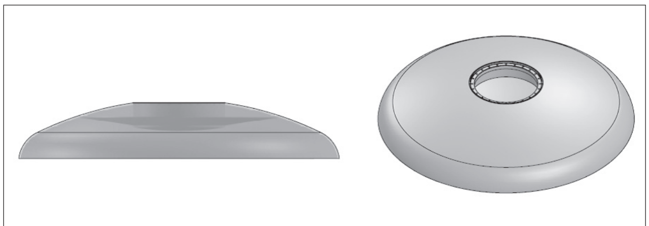

Fig. 6. Model of the mixer drum bottom

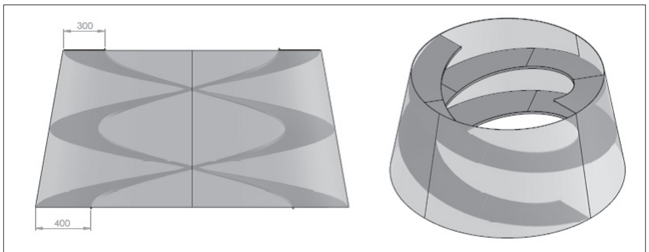

Fig. 7. Intermediate cone model of the mixer drum

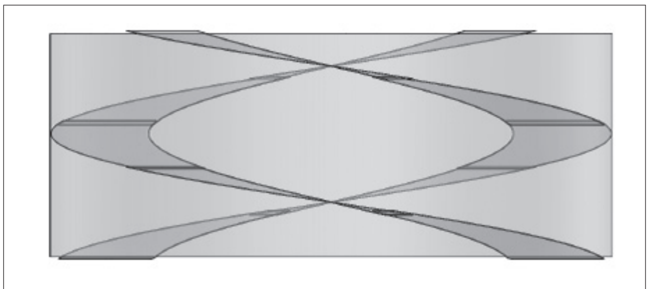

Fig. 8. Model of the mixer drum cylinder

Figure 8 shows a model of an intermediate cone with the marked outline of the helical line of the two inner assemblies of mixing-unloading spiral segments permanently welded to the cone.

A model of the cylinder with the marked outline of the screw line of the two inner assemblies of the mixing-unloading spiral segments permanently joined by a welded joint to the inner of cylinder shell is shown in fig. 8.

Figure 9 shows a model of the auxiliary cone with the outline of the screw line and the width dimension of the internal mixing-unloading spirals, which, analogous to the previous drum components, are permanently connected to the inner side using a welded joint.

Figure 10 shows a model of the rear cone with the marked outline of the helical line of the two inner assemblies of mixing-unloading spiral segments welded to the inner side of the cone shell

Figure 11 shows a model of a small cone with a marked outline of the helical line of the two inner assemblies of mixing-unloading spiral segments welded to the inner side of the cone shell.

Models of the cone and cylinder assemblies of the innovative mixing drum with a capacity of 12 m³ – shell segments and mixing-unloading spiral together with

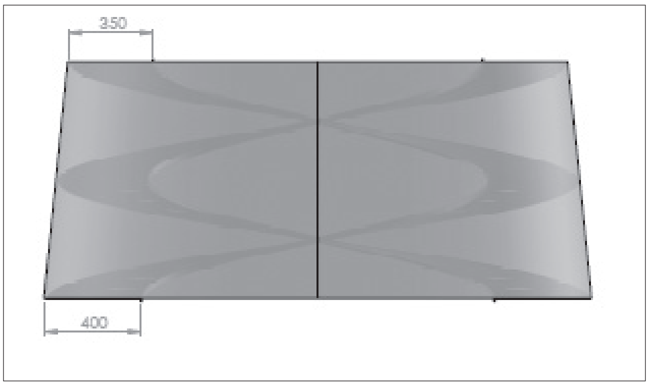

Fig. 9. Model of the auxiliary cone of the mixer drum

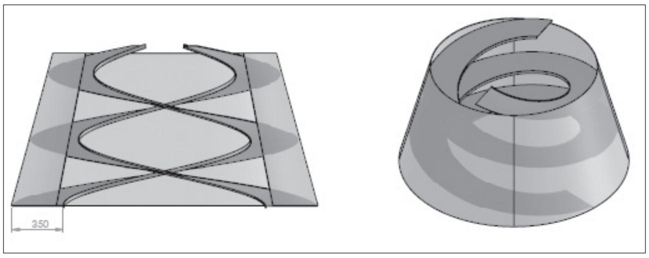

Fig. 10. Model of the rear cone of the mixer drum

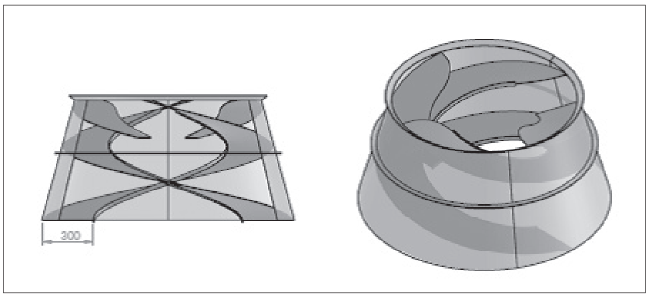

Fig. 11. Cone model of minor mixer drum

a description of the individual components are shown in fig. 12 and 13 (the number varies depending on the size of the cone).

Special attention was paid to the development of an innovative mixing and unloading spiral of the 12 m^3 mixer drum, which is the key element responsible for the correct and efficient production/mixing of concrete mass during transport by a hydraulic truck concrete mixer. The design of the spiral is shown in fig. 14.

The spiral segments located in the area of each segment of the 12 m^3 mixer drum were analyzed in detail (fig. 15–18).

The mixing and unloading spiral is an element of the mixer drum particularly exposed to damage resulting from the pressure of the concrete mass on its elementary segments and due to the friction properties of concrete, especially mixtures for special purposes.

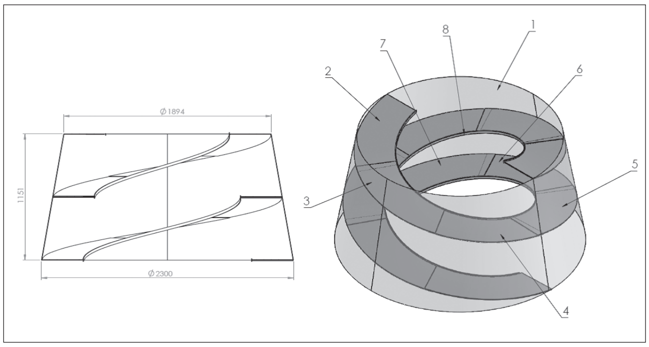

Fig. 12. Model of the mixer drum cone assembly – shell and spiral segments: *1* – outer shell, *2–7* – spiral segments, *8* – cooper

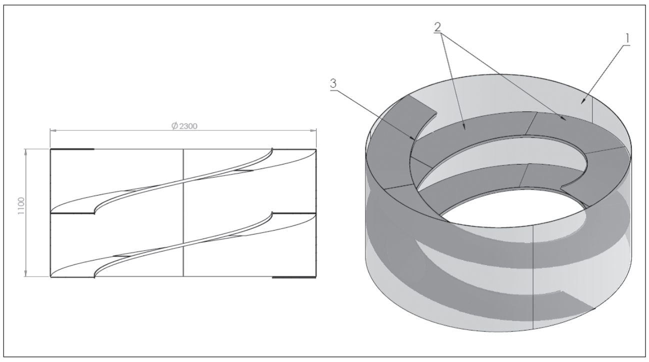

Fig. 13. Model of the mixer drum cylinder assembly – shell and spiral segments: *1* – outer shell, *2* – spiral segments, *3* – cooper

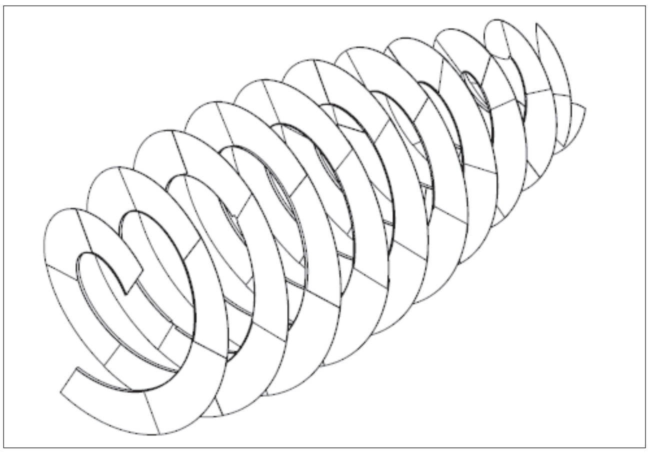

Fig. 14. Model of the mixing-unloading spiral segment assembly

Therefore, an innovative spiral design was developed, with its individual segments having the above-mentioned individual dimensional and shape conditions and the assumed use in the production process of sheets with increased strength parameters, especially abrasion resistance, as presented in the table.

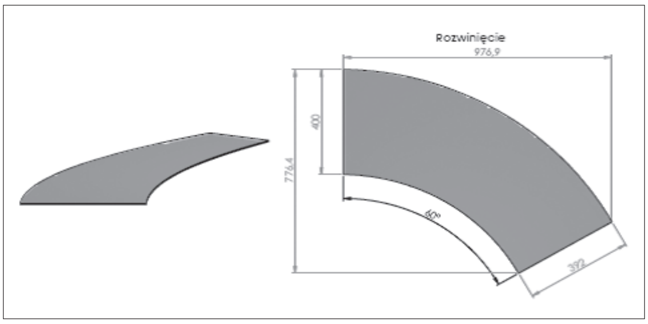

Fig. 15. Spiral segment of the intermediate cone

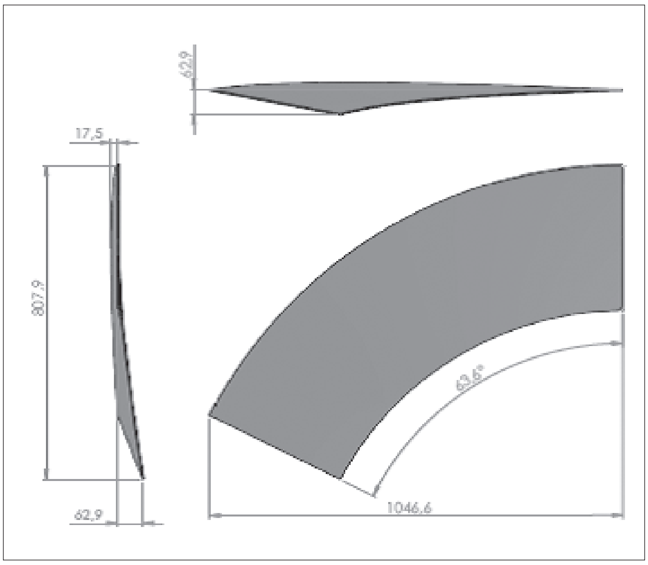

Fig. 16. Cylinder spiral segment

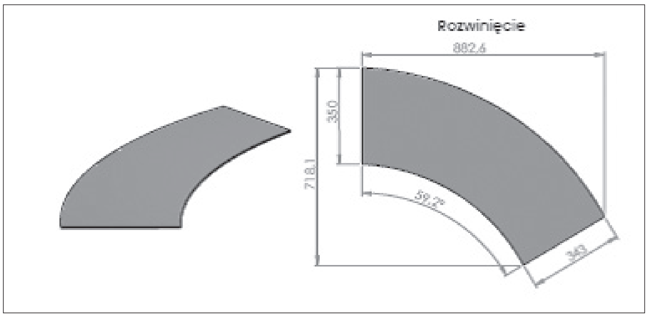

Fig. 17. Rear cone spiral segment

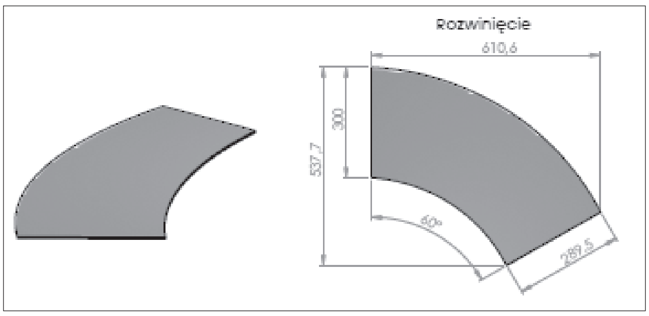

Fig. 18. Minor cone spiral segment

Conclusion

Selected results of research work developed in the article confirm the design assumptions adopted for individual segments of the innovative mixer drum. The construction of the components of the mixing and discharging spiral and the drum shell was developed and verified. Modeling in the advanced environment of the CAD system was focused on the possibility of application in the production process of the mixer selected by material analysis of three steel grades with increased strength parameters, including primarily abrasion resistance. In addition, an extremely important factor in the process of generating CAD models were individual technological operations individually developed for each segment of the spiral and drum shell for the production of research prototypes of the mixer provided for in the project.

Particular attention was paid to the construction of the mixing and unloading spiral, which is an element responsible for the correct and efficient implementation of the process of production/mixing of concrete mix. The construction of its individual segments was developed in terms of improving functionality and extending the service cycle – the product life cycle. In order to verify the structural assumptions and generated CAD models of spiral segments, numerical analysis of stress distribution using FEM was developed and carried out. The determined results confirmed the correctness of the construction – individual parameters, including above all the safety factor, guarantee proper operation of the spiral without the risk of damage resulting from design and construction reasons. Its minimum value set in FEM tests at the level of 4.4 is adequate or even higher than assumed for this type of construction, the more that it concerns the steel grade with the lowest strength parameters among the sheets selected by material analysis for the production of an innovative drum of a hydraulic mixer of a concrete mixer with a capacity of 12 m^3.

The developed analysis of the test results presented in this publication enables the implementation of the next stage of work, i.e. the production of prototypes of the innovative 12 m^3 mixer drum and the conduct of bench tests of the structure.

Acknowledgements

The research was carried out as part of the project RPPK.01.02.00-IZ-00-18-012/19 entitled „Research and development work for the design and manufacture of an innovative mixer drum with a capacity of 12 m^3", co-financed by the European Regional Development Fund.

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