



## EFFECT SIZES IN CONTACT FATIGUE

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### Abstract

The results of special experiments on the size effect in contact fatigue are presented. It is established that under constant contact loading conditions the durability is higher, the larger is the diameter of a tested element. The methods for estimation of contact fatigue resistance of gear wheels, which is based on the statistical model for a deformable solid body having a critical volume, are

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proposed. The limiting stresses of a gear wheel are estimated using a regulated base for this machine parts.

**Keywords:** size effect, contact fatigue, gear wheels.

## Introduction

The durability and fatigue resistance of components operating under cyclic loading by bending, tension, compression, twisting, etc. appear to be the lower, the larger are the component dimensions [1, 2]. Since the phenomena of contact fatigue are based on the same processes as those occurring under other types of fatigue, it is natural to expect that increasing the absolute dimensions of a component would decrease its contact fatigue limit. However, by analyzing the available results of studies on the size effect in contact fatigue it is impossible to get a definite opinion on this problem [2-13].

Some researchers state that the size effect in contact fatigue undergoes inversion, i.e., as the diameter of contacting parts is increased, the durability grows [4-6]. However, others assert that increase in a component size leads to reduction of bending and contact fatigue limits [7, 10].

For the basic regularities of the size effect in contact fatigue to be elucidated, special experimental studies have been made. The test scheme is shown in Figure 1. Cylindrical sample 2 serves as a tooth of a gear wheel. A counter body — roller 1 — is pressed to the surface of sample 2 by a contact load  $F_N$  in the contact zone  $x$ .

Roller 1 serves as a tooth of the second gear wheel that transmits the contact load  $F_N$  to sample-model 2.

Sample 2, which is fastened in spindle 3, is rotated with an angular velocity  $m_1$ . Counter body 1 is rotated with an angular velocity in 2, its rotation axis being parallel to that of sample 2. Regulating the ratio of the velocities  $m_1$  and  $in_2$  allows one to obtain the required slip coefficient, imitating the slip in gearing.

The contact load  $F_N$  provides a simultaneous excitation both of contact and bending stresses in the corresponding zones, whereas the distance between these zones is chosen to be equal to that between the pitch point and the tooth root.

Using the counter body (roller) with a constant diameter  $D$  100 mm and sample-models of various diameters  $d$  (Fig. 2) makes it possible to change two main curvatures and to obtain the size ratio of the contact area ( $a/b$ ) within the range 0.4-0.8, which is satisfactory for practical purposes.

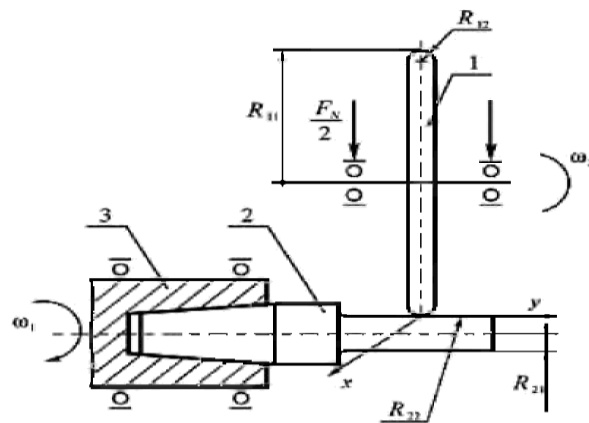


Figure 1. Testing scheme for a toothed gearing model: (1) sample-model of the tooth; (2) counterbody (roller); (3) testing machine spindle.

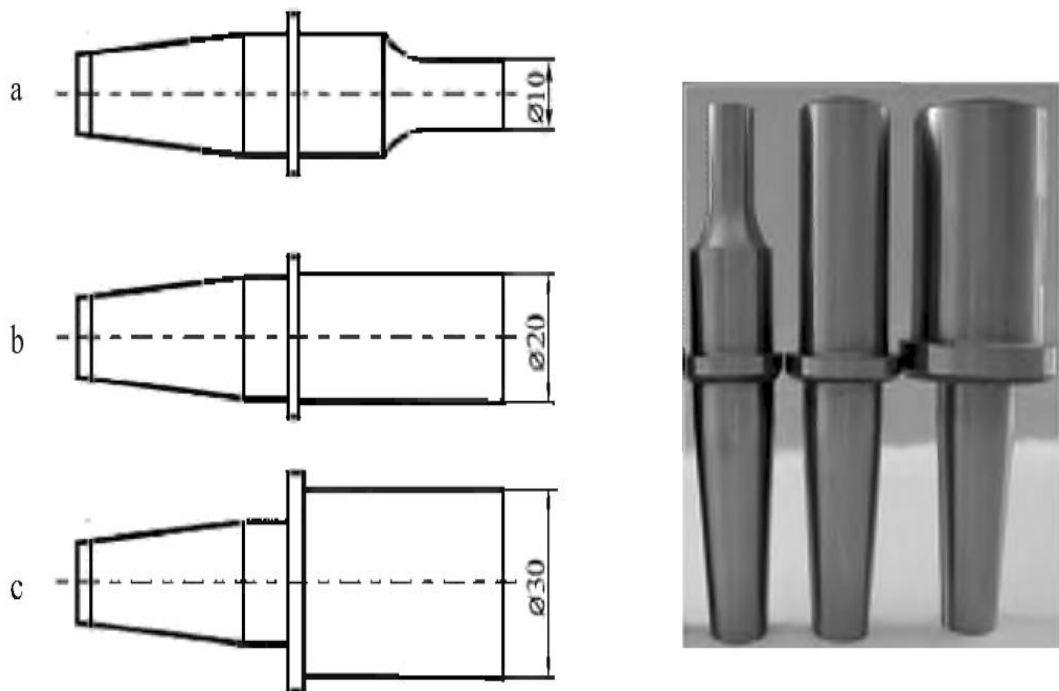


Figure 2. Tested tooth models.

Samples 10, 20, and 30 mm in diameter were made from steel 18KhGT, invoking the technology of manufacturing gear wheels at the Production Group “Gomselmash.” Working surfaces of counterbodies and samples were cemented at a depth of 1.0-1.5 mm with subsequent hardening up to 59-63 HRC and polished ( $R_a > 0.32 \mu\text{m}$ ). The run-out of the samples in the working zone was not more than 10  $\mu\text{m}$ . Tests were performed using a wear fatigue testing machine of UIM type [20] at a constant linear velocity in the contact  $v_{\text{circ}} = 1.57 \text{ m/s}$ . The

error of keeping the shaft rotation frequency within the steady regime is  $\pm 3\%$  of the measured value [20].

When the sample and the counterbody are tested in the contact zone, the slip degree is controlled to be equal to 3%. In the course of tests, a lubricant (oil TAD-17 I) is supplied to the contact zone with a feeding speed of 2 -4 drops per minute. The tests were interrupted after occurrence of the limiting state conditions corresponding to the real service ones for a particular gearing (limiting convergence of the axes of the sample and the counterbody  $\delta_{lim} = 100 \mu\text{m}$ ). The contact load  $F_N$  (see Figure 3) serves as a parameter controlling the model loading.

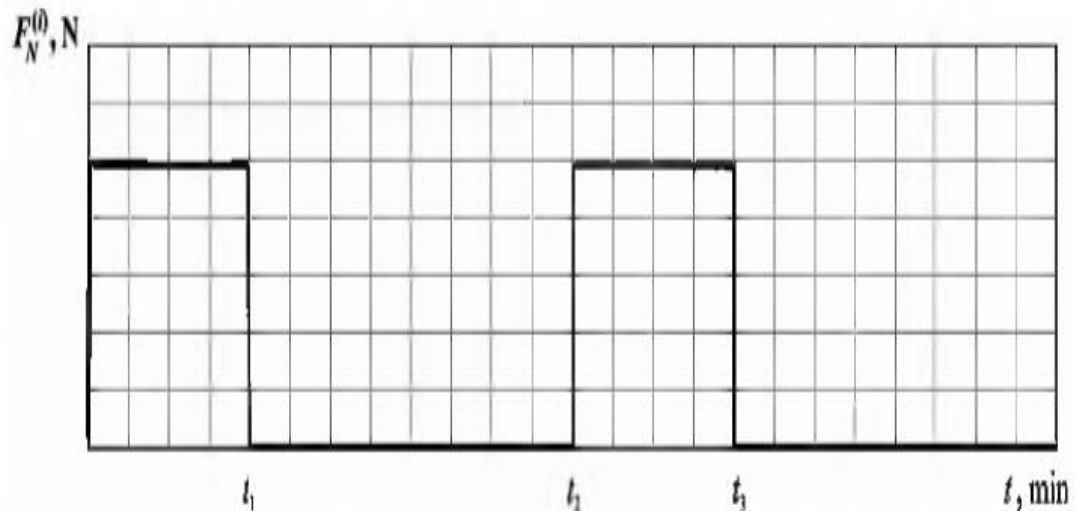


Figure 3. Loading program scheme.

The basic test results are shown in Figures. 4 and 5. From Figure 4 it is seen that under constant contact loading conditions the durability is higher, the larger is the diameter of a tested element. For the base of  $N_b = 4 \cdot 10^6$  cycles, we have established the dependences of limiting contact stresses  $p_f$  and limiting contact load  $F_{lim}$  on the diameter of the tested models,  $d$  (Figure 5). The analysis of Figure 5 yields that:

- 1) in terms of the limiting contact load, if the tested model diameter is increased from 10 to 30 mm, this load grows from 780 to 1520 N.
- 2) in terms of the limiting contact fatigue, if the tested model diameter is increased from 10 to 30 mm, the contact fatigue limit decreases from 5150 MPa to 4900 MPa.

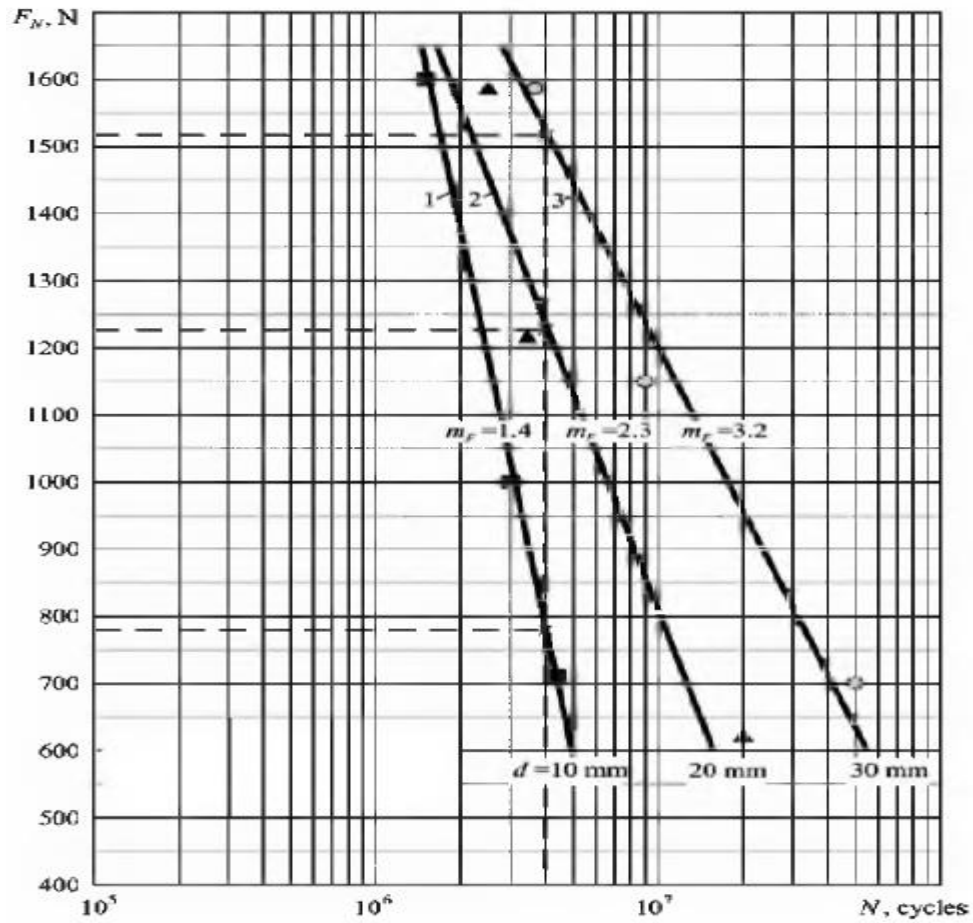


Figure 4. The size effect on the contact fatigue resistance [(1)  $\log F = 7.8009 - 0.7434 \log N$ ; (2)  $\log F = 5.9047 - 0.4266 \log N$ ; (3)  $\log F = 5.2255 - 0.3097 \log N$ ].

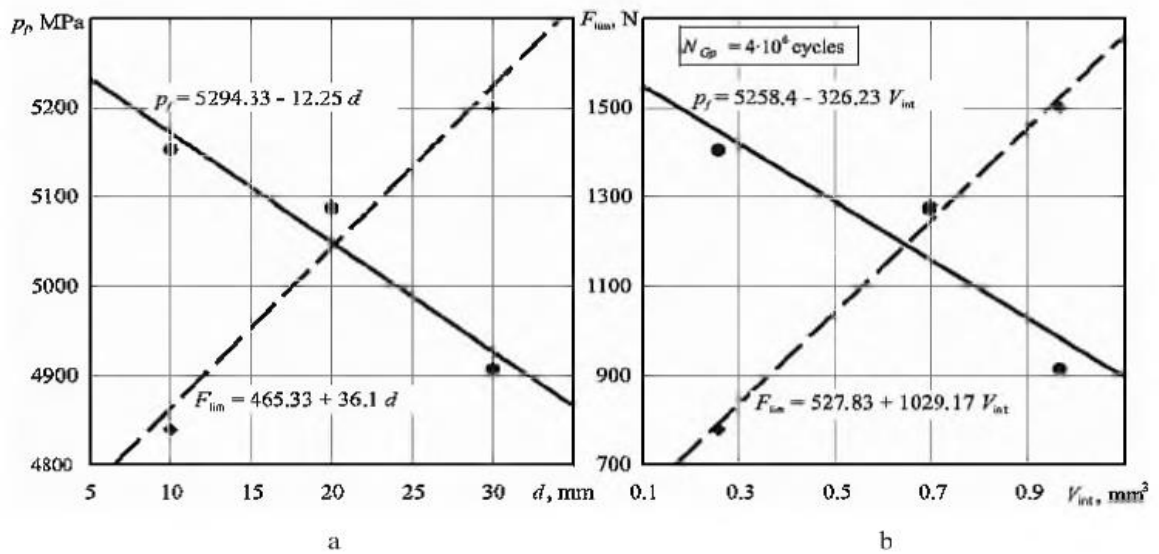


Figure 5. Limiting contact stresses and limiting contact load vs. sample diameter (a) and critical volume size (b).



Based on the above experimental results, it is possible to formulate the following basic regularity of the size effect in friction: under constant contact loading conditions the durability is higher, the larger is the diameter of a tested component. For the size effect in contact fatigue to be analyzed theoretically, the model of a solid body with a critical volume [14] was used. According to this model, if a deformable solid body is characterized by such a stressed state that its fatigue failure is possible, then it is composed of two regions: safe and critical volumes. Similarly, assume that in contact deformation by a critical volume  $V_{int}$  is understood the region of a loaded body, at each point of which the value of the stress intensity  $\sigma_{int}$  is less than the limiting value of  $\sigma_{int}^{(lim)}$  ( $\sim p_f^{(lim)}$ )

$$V_{int} = \int \int \int_{\sigma_{int}(x,y,z) \geq \sigma_{int}^{lim}} dx dy dz. \tag{1}$$

The critical volume is an absolute measure of damage; it is statistical in character and contains the geometrical sizes of tested elements. This permit using it as the parameter controlling the size effect in contact fatigue. The proposed procedure is applied for the assessment of critical (limiting) stresses as a limitation criterion for the corresponding critical regions [15]. It  $\sigma_{int}^{(*lim)}$  consists in determining the limiting intensity of stresses  $\sigma_{int}$  when the tested system is subjected to the limiting load  $F * lim$ :

$$\sigma_{int}^{(*lim)} = \max_{dV}(\sigma_{int}(F * lim, dV),) \tag{2}$$

where  $dV$  is the elementary volume of the loaded body.

Then the criterial condition for limitation of critical volumes will be of the form

$$V_{int} = \{dV / \sigma_{int} \geq \sigma_{int}^{(*lim)}, dV \subset V_k\}, \tag{3}$$

where  $V_k$  is the working volume of a deformable solid body. As critical volumes can have arbitrary and complex shapes, it is difficult to determine them by formula (1). Therefore, calculations were made using the program package “Mathematics”

by the numerical Monte-Carlo method. Figure 6 presents the calculation results on the critical volumes formed due to normal and tangential contact stresses.

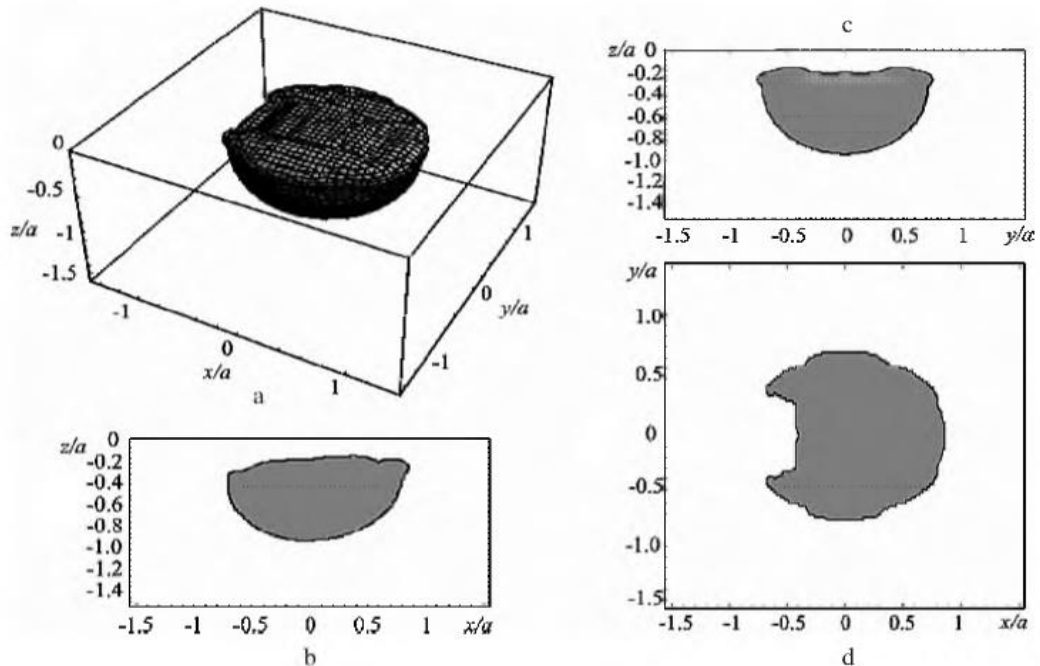


Figure 6. The critical volume (a) developed due to normal and tangential contact stresses: (b) section by the plane  $y = 0$ ; (c) section by the plane  $x = 0$ ; (d) section by the plane  $z = 0.5a$

Since critical volumes are used as the damage measure of deformable bodies, the analysis of Figure 6 specifies the particular regions (zones) where internal cracks can initiate and propagate.

Using the proposed method, the dependences of limiting contact stresses  $p_f$  and limiting contact load  $F_{lim}$  on the critical volume size ( $V_{int}$ ) (Figure 5) are constructed for the base  $N_b = 4 \cdot 10^6$  cycles. The obtained dependences are seen to have a qualitatively similar character both in analyzing the tested models in terms of the diameter and the critical volume in terms of size. Thus, the proposed model is valid and does not contradict the results obtained. In this case, a critical volume to be calculated includes the geometrical dimensions of tested components and has a statistical character [limiting contact stresses  $p_f^{(lim)}$ ] serve as a limitation criterion]. In this respect, this is a more preferable parameter for description of the size effect in contact fatigue.

Using the given approach, it is possible to execute a settlement estimation of rolling fatigue resistance of particular toothed gear wheels. The input data for calculations are given in Table 1.

Table 1. Input Data for Calculation of Gear Wheels

Gear	Combined torque $M_k \cdot N \cdot m$	Reference diameter $d$	Radius of tooth profile evolvent in a pitch point		Effective face width $B$ , mm
			$\rho_1$ , mm	$\rho_2$ , mm	
PKK 0135684	290	92	15.73	19.15	20
PKK 0135661	450	108	18.47	21.89	40

For the rolling fatigue limit estimation for a particular type cogwheel it is necessary to pass to base of tests equal to  $1.2 \cdot 10^8$  cycles which is regulated for tooth gearings [10, 17]. As a first approximation, such transition can be executed, accepting the slope indicator of the left branch of rolling fatigue curve  $m_p = 3-6$  [17] or on the average  $m_p = 4.5$ . Calculation results are presented in Figure 7 and in

Table 2.

Table 2 Results of Calculation of Gear Wheels

Gear	$V_{int}$ , $mm^3$	$p_0$ , MPa	$p_f$ , MPa	$n_p$	$\sigma_H$ , MPa	$n_{\sigma_H}$
PKK 0135684	0.00201	1171.4	2340.8	2.00	1337.8	1.75
PKK 0135661	0.00208	888.6	2340.3	2.63	945.7	2.47

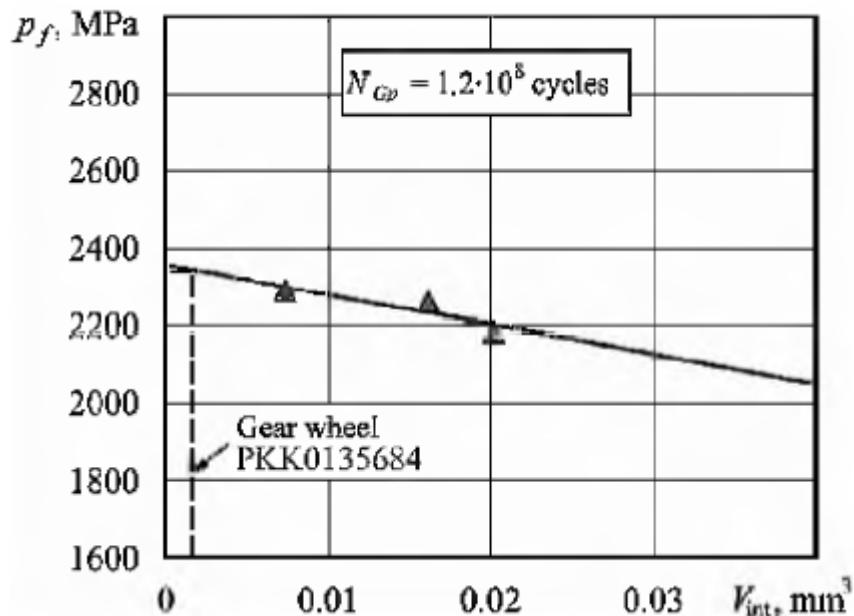


Figure 7. Dependence of rolling fatigue limit on the critical volume value. It is seen from Table 2 that for a gear wheel PK K 0135684 value of safety factor for the rolling endurance  $n_p$  is lower by 25% than that of PK K 0135661. This allows us to conclude that the operational durability of the PKK 0135684 gear





wheel will also be lower than that of PKK 0135661. This conclusion is confirmed by data on operation of a transmission PKK 0135000 of a harvest combine “Polesie-3000” manufactured by Production Group “Gomselmash” [22].

## Conclusions

Inversion of size effect in rolling fatigue is established and described for particular experimental conditions. The technique of rolling fatigue resistance assessment on the basis of statistical model of a deformable solid body with critical volume is proposed. The estimation of a rolling fatigue limit is made for particular types of gear wheels.

## References

1. Семин, А. Е., Турсунов, Н. К., & Косырев, К. Л. (2017). Инновационное производство высоколегированной стали и сплавов. Теория и технология выплавки стали в индукционных печах.
2. Нурметов, Х. И., Турсунов, Н. К., Кенжаев, С. Н., & Рахимов, У. Т. (2021). ПЕРСПЕКТИВНЫЕ МАТЕРИАЛЫ ДЛЯ МЕХАНИЗМОВ АВТОМОБИЛЬНЫХ АГРЕГАТОВ. *Scientific progress*, 2(2), 1473-1479.
3. Tursunov, N. K., Semin, A. E., & Sanokulov, E. A. (2016). Study of desulfurization process of structural steel using solid slag mixtures and rare earth metals. *Chernye metally*, 4, 32-7.
4. Турсунов, Н. К., Тоиров, О. Т., Железняков, А. А., & Комиссаров, В. В. (2021). Снижение дефектности крупных литых деталей подвижного состава железнодорожного транспорта за счет выполнения мощных упрочняющих рёбер.
5. Турсунов, Н. К., Санокулов, Э. А., & Семин, А. Е. (2016). Исследование процесса десульфурации конструкционной стали с использованием твердых шлаковых смесей и РЗМ. *Черные металлы*, (4), 32-37.
6. Tursunov, N. K., Semin, A. E., & Sanokulov, E. A. (2017). Study of dephosphoration and desulphurization processes in the smelting of 20GL steel in the induction crucible furnace with consequent ladle treatment using rare earth metals. *Chernye Metally*, 1, 33-40.
7. Турсунов, Н. К., Семин, А. Е., & Котельников, Г. И. (2017). Кинетические особенности процесса десульфурации при выплавке стали в индукционной тигельной печи. *Черные металлы*, (5), 23-29.



8. Турсунов, Н. К., Семин, А. Е., & Саноккулов, Э. А. (2017). Исследование процессов дефосфорации и десульфурации при выплавке стали 20ГЛ в индукционной тигельной печи с дальнейшей обработкой в ковше с использованием редкоземельных металлов. Черные металлы, (1), 33-40.
9. Toirov, O. T., Tursunov, N. Q., Nigmatova, D. I., & Qo'chqorov, L. A. (2022). USING OF EXOTHERMIC INSERTS IN THE LARGE STEEL CASTINGS PRODUCTION OF A PARTICULARLY. Web of Scientist: International Scientific Research Journal, 3(1), 250-256.
10. Турсунов, Н. К., & Тоиров, О. Т. (2021). Снижение дефектности рам по трещинам за счёт применения конструкции литниковой системы.
11. Тоиров, О. Т., Турсунов, Н. К., Кучкоров, Л. А., & Рахимов, У. Т. (2021). ИССЛЕДОВАНИЕ ПРИЧИН ОБРАЗОВАНИЯ ТРЕЩИНЫ В ОДНОЙ ИЗ ПОЛОВИН СТЕКЛОФОРМЫ ПОСЛЕ ЕЁ ОКОНЧАТЕЛЬНОГО ИЗГОТОВЛЕНИЯ. Scientific progress, 2(2), 1485-1487.
12. Tursunov, N. K., Semin, A. E., & Sanokulov, E. A. (2017). Research of dephosphorization and desulfurization processes in smelting of 20GL steel in an induction crucible furnace with further processing in a ladle using rare earth metals. Chern. Met., 1, 33-40.
13. Тен, Э. Б., & Тоиров, О. Т. (2021). Оптимизация литниковой системы для отливки. Литейное производство, (10), 17-19.
14. Тен, Э. Б., & Тоиров, О. Т. (2020). Оптимизация литниковой системы для отливки «Рама боковая» с помощью компьютерного моделирования. In Прогрессивные литейные технологии (pp. 57-63).
15. Азимов, Ё. Х., Рахимов, У. Т., Турсунов, Н. К., & Тоиров, О. Т. (2022). Исследование влияние катионов солей на реологический статус геллановой камеди до гелеобразования. Oriental renaissance: Innovative, educational, natural and social sciences, 2(Special Issue 4-2), 1010-1017.
16. Тоиров, О. Т. У., Турсунов, Н. К., & Кучкоров, Л. А. У. (2022). Совершенствование технологии внепечной обработки стали с целью повышения ее механических свойств. Universum: технические науки, (4-2 (97)), 65-68.
17. Riskulov, A. A., Yuldasheva, G. B., Kh, N., & Toirov, O. T. (2022). DERIVATION PROCESSES OF FLUORINE-CONTAINING WEAR INHIBITORS OF METAL-POLYMER SYSTEMS. Web of Scientist: International Scientific Research Journal, 3(5), 1652-1660.



18. Рахимов, У. Т., Турсунов, Н. К., Кучкоров, Л. А., & Кенжаев, С. Н. (2021). ИЗУЧЕНИЕ ВЛИЯНИЯ ЦИНКА Zn НА РАЗМЕР ЗЕРНА И КОРРОЗИОННУЮ СТОЙКОСТЬ СПЛАВОВ СИСТЕМЫ Mg-Nd-Y-Zr. *Scientific progress*, 2(2), 1488-1490.
19. Нурметов, Х. И., Турсунов, Н. К., Туракулов, М. Р., & Рахимов, У. Т. (2021). УСОВЕРШЕНСТВОВАНИЕ МАТЕРИАЛА КОНСТРУКЦИИ КОРПУСА АВТОМОБИЛЬНОЙ ТОРМОЗНОЙ КАМЕРЫ. *Scientific progress*, 2(2), 1480-1484.
20. Tursunov, N. K., & Ruzmetov, Y. O. (2018). Theoretical and experimental analysis of the process of defosphoration of steel used for parts of the mobile composition of railway transport. *Journal of Tashkent Institute of Railway Engineers*, 14(2), 60-68.
21. Тоиров, О. Т., Кучкоров, Л. А., & Валиева, Д. Ш. (2021). ВЛИЯНИЕ РЕЖИМА ТЕРМИЧЕСКОЙ ОБРАБОТКИ НА МИКРОСТРУКТУРУ СТАЛИ ГАДФИЛЬДА. *Scientific progress*, 2(2), 1202-1205.
22. Турсунов, Н. К., Уразбаев, Т. Т., & Турсунов, Т. М. (2022). Методика расчета комплексного раскисления стали марки 20Гл с алюминием и кальцием. *Universum: технические науки*, (2-2 (95)), 20-25.
23. Toirov, B. T., Jumaev, T. S., & Toirov, O. T. (2021). OBYEKT LARNI TANIB OLISHDA PYTHON DASTURIDAN FOYDALANISHNING AFZALLIKLARI. *Scientific progress*, 2(7), 165-168.
24. ТУРСУНОВ, Н. (2021). Повышение качества стали за счет применения редкоземельных металлов. ВЯ Негрей, ВМ Овчинников, АА Поддубный, АВ Пигунов, АО Шимановский, 158.
25. Турсунов, Н. К. (2022). Исследование режимов рафинирования стали, используемые для изготовления литых деталей подвижного состава железнодорожного транспорта. *Лучший инноватор в области науки*, 1(1), 667-673.
26. Riskulov, A. A., Yuldasheva, G. B., & Toirov, O. T. (2022). FEATURES OF FLUOROCOMPOSITES OBTAINING FOR WEARING PARTS OF MACHINE-BUILDING PURPOSE. *Web of Scientist: International Scientific Research Journal*, 3(5), 1670-1679.
27. Risqulov, A. A., Sharifxodjayeva, X. A., Tursunov, N. Q., & Nurmetov, X. I. (2022). Transport sohasi uchun mutaxassislarni tayyorlashda materialshunoslik yo 'nalishining o 'rni va ahamiyati. *Academic research in educational sciences*, 3(TSTU Conference 1), 107-112.



28. Riskulov, A. A., Yuldasheva, G. B., Kh, N., & Toirov, O. T. (2022). DERIVATION PROCESSES OF FLUORINE-CONTAINING WEAR INHIBITORS OF METAL-POLYMER SYSTEMS. Web of Scientist: International Scientific Research Journal, 3(5), 1652-1660.