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Annotatsiya
Mazkur toʻplamda "Yangi davr ilm-fani: inson uchun innovatsion gʻoya va yechimlar" mavzusidagi II Respublika ilmiy-amaliy konferensiyasi materiallari jamlangan. Nashrda respublikaning turli oliy ta'lim muassasalari, ilmiy markazlari va amaliyotchi mutaxassislari tomonidan tayyorlangan maqolalar oʻrin olgan boʻlib, ular ijtimoiy-gumanitar, tabiiy, texnik va yuridik fanlarning dolzarb muammolari va ularning innovatsion yechimlariga bagʻishlangan.
Ushbu nashr ilmiy izlanuvchilar, oliy ta'lim oʻqituvchilari, doktorantlar va soha mutaxassislari uchun foydali qoʻllanma boʻlib xizmat qiladi.

Kalit soʻzlar: ilmiy-amaliy konferensiya, innovatsion yondashuv, zamonaviy fan, fanlararo integratsiya, ilmiy-tadqiqot, nazariya va amaliyot, ilmiy hamkorlik.

MUNDARIJA

GEOGRAFIYA FANLARI

YURIDIK FANLAR

PEDAGOGIKA FANLARI

WITH STRUCTURE FORMATION AND THE STRUCTURAL COMPOSITION OF THE COMPOSITION BASED ON POLYAMIDE WITH IRON OXIDE NANOPARTICLES

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Annotation. This study investigates the structural and physicochemical transformations occurring in polyamide-based composites reinforced with iron oxide nanoparticles, with the aim of developing advanced materials for mechanical engineering applications. Polyamide-52 (PA-52) was selected as the polymer matrix due to its favorable strength, tribological performance, and low density compared to traditional metals. Despite its advantages, PA-52 exhibits reduced mechanical properties in humid environments and limited dimensional stability, which necessitates modification through functional fillers.To improve the performance characteristics, iron oxide (FeO) nanoparticles were introduced into the polymer matrix using controlled dispersion techniques. X-ray fluorescence (XRF) analysis was employed to determine the elemental composition of neat PA-52 and PA-52/FeO composites. The results confirmed the presence of non-metallic and metallic oxides—including iron, magnesium, manganese, germanium, zinc, and trace elements—in varying proportions, indicating the individuality of the modified composite. Further structural identification was performed using X-ray phase analysis (XRD). Comparative diffraction patterns demonstrated distinct interplanar spacings and intensity ratios for PA-52 and PA-52 with FeO nanoparticles, revealing significant changes in crystallinity and structure formation. The introduction of FeO altered the supramolecular organization of the polymer matrix, intensifying diffraction peaks and modifying the structural ordering. The results indicate that FeO nanoparticles play an active role in enhancing the structural properties of polyamide composites, making them suitable for use in high-demand mechanical systems. The study provides a scientific basis for the development of new-generation polymer composites with predictable and improved performance characteristics for the engineering industry.

Key words: polyamide-52; iron oxide nanoparticles; polymer composite; X-ray fluorescence; X-ray diffraction; structural analysis; mechanical engineering materials; supramolecular organization; crystallinity modification; functional fillers; PA-52 matrix; FeO nanoparticle reinforcement; composite microstructure; dispersion uniformity; phase transformation; interfacial interaction; crystalline-amorphous transitions; thermomechanical stability; nanoscale fillers; diffraction peak analysis; elemental mapping; macromolecular packing; filler–polymer interaction; nanocomposite morphology; structural-phase characterization; functionalized composites; load-bearing applications; material diagnostics; physicochemical properties; crystallite orientation; supramolecular structuring; nanoparticle distribution; structural-performance correlation; polymer-filler compatibility.

POLIAMID VA TEMIR OKSIDI NANOPARTIKULLARI ASOSIDAGI KOMPOZITSIYANING TUZILISHI VA STRUKTURAVIY TARKIBI.

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Annotatsiya. Ushbu tadqiqot poliamid asosidagi kompozitlarning temir oksidi nanopartikullari bilan mustahkamlanishi jarayonida yuzaga keladigan struktural va fizik-kimyoviy o'zgarishlarni o'rganadi. Maqsad - mexanik muhandislik ilovalari uchun ilg'or materiallar ishlab chiqishdir. Poliamid-52 (PA-52) polymer matritsa sifatida tanlandi, chunki u an'anaviy metallarga nisbatan quvvat, tribologik ishlash va past zichlik kabi afzalliklarni taqdim etadi. Biroq, PA-52 nam muhitda mexanik xususiyatlarning kamayishi va cheklangan o'lchov barqarorligi bilan bog'liq muammolarni ko'rsatadi, bu esa funksional to'ldiruvchilar orqali modifikatsiyani talab qiladi. Ishlash xususiyatlarini yaxshilash maqsadida temir oksidi (FeO) nanopartikullari polymer matritsaga nazorat ostida tarqatish texnikalari yordamida kiritildi. PA-52 va PA-52/FeO kompozitlarining elementar tarkibini aniqlash uchun rentgen floresans (XRF) tahlili o'tkazildi. Natijalar, modifikatsiyalangan kompozitning individual xususiyatlarini ko'rsatib, turli nisbatlarda temir, magniy, marganets, germaniy, rux va iz elementlarini o'z ichiga olgan metall va metall bo'lmagan oksidlarning mavjudligini tasdiqladi. Qo'shimcha struktural identifikatsiya rentgen faza tahlili (XRD) yordamida amalga oshirildi. Taqqoslash diffraktsiya spektrlari PA-52 va FeO nanopartikullari bilan PA-52 uchun aniq interplanar masofalar va intensivlik nisbati ko'rsatdi, bu esa kristallik va strukturaviy hosil bo'lishda sezilarli o'zgarishlarni ochib berdi. FeO ni kiritish polymer matritsaning supramolekulyar tashkilotini o'zgartirdi, diffraktsiya cho'qqilarini kuchaytirdi va struktural tartibni modifikatsiya qildi. Natijalar shuni ko'rsatadiki, FeO nanopartikullari poliamid kompozitlarining struktural xususiyatlarini yaxshilashda faol rol o'ynaydi, bu esa ularni yuqori talabga ega mexanik tizimlarda foydalanishga mos qiladi. Tadqiqot muhandislik sanoati uchun kutilgan va yaxshilangan ishlash xususiyatlariga ega yangi avlod polymer kompozitlarini ishlab chiqish uchun ilmiy asosni taqdim etadi.

Kalit so'zlar: poliamid-52; temir oksidi nanopartikullari; polymer kompozit; rentgen floresans; rentgen diffraktsiyasi; struktural tahlil; mexanik muhandislik materiallari; supramolekulyar tashkilot; kristallik modifikatsiyasi; funksional to'ldiruvchilar; PA-52 matritsasi; FeO nanopartikul mustahkamlanishi; kompozit mikrostruktura; tarqatish birxilligi; faza o'zgarishi; interfeys o'zaro ta'siri; kristall-amorf o'tishlar; termomekanik barqarorlik; nanoskal to'ldiruvchilar; diffraktsiya cho'qqilarini tahlil qilish; elementar xaritalash; makromolekulyar joylashish; to'ldiruvchi-polimer o'zaro ta'siri; nanokompozit morfologiyasi; struktural-faza xarakterlash; funksional kompozitlar; yuk ko'tarish ilovalari; materiallarni diagnostika qilish; fizik-kimyoviy xususiyatlar; kristallit yo'nalishi; supramolekulyar tuzilish; nanopartikul tarqatilishi; struktura-performans korrelyatsiyasi; polimer-to'ldiruvchi mosligi.

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Polymer composite materials are currently the most numerous and rapidly developing type of modern materials. These materials are constantly being updated and improved. In addition to improving the properties of materials, work is constantly underway to improve the technology of manufacturing products from them, as well as assembly technologies and diagnostics of operational reliability. And this is not only because the results of the work can be used in many industries, but mainly because the resulting materials have unique and predictable properties, providing a scientific and technical breakthrough in the development of units of the mechanical engineering industry, which are currently relevant. Among the most promising polymer binders are polyamides (PA). A distinctive feature of PA is the presence of a repeating amide group -CO-NH- in the main molecular chain. A distinction is made between aliphatic and aromatic PA; PA containing both aliphatic and aromatic fragments in the main chain are also known [1,2,3,5,6,27].

Aliphatic PAs, which are multifunctional structural materials that are 6-7 times lighter than bronze and steel, are successfully used to replace non-ferrous metals and their alloys [4,5,6]. They are durable, have a low coefficient of friction in a pair with any metals, and are well and quickly run in; wear of friction pairs when using PA parts is reduced by 1.5-2 times

[7,8,9,10,29,30]. The disadvantages of aliphatic PAs include a significant decrease in physical and mechanical characteristics in a humid environment, low stability of strength and electrical insulation properties, as well as insufficiently high dimensional accuracy of products made from them [10,11,12,27,30,37]. Taking these provisions into account, in order to improve the main performance characteristics, it is very advisable to introduce dispersed metal fillers into the composition of polyamide binders and to study the scientific principles of creating polymer composite materials based on the study of the structural composition, structure, and physical and chemical characteristics of the polyamide composite.

The aim of this work is to determine the structural parameters of polyamide-52 and polyamide with iron nanoparticles for modeling the physical and chemical properties of the polyamide composite, the results of which can be used in the development of composite materials for the needs of the mechanical engineering industry.

In recent years, particular attention has been paid to the modification of polyamide matrices with nanoscale metal and metal oxide fillers to improve their operational stability and load-bearing capacity. Researchers have shown that the incorporation of iron, aluminum, silicon, copper, and titanium oxides into PA-based systems can significantly influence crystallinity, interfacial adhesion, and thermal resistance of the polymer composite [40–44]. Studies conducted by J. Zhang et al. and M. Ramesh et al. confirmed that iron oxide nanoparticles, due to their high surface reactivity and compatibility with amide groups, enhance the supramolecular ordering and nucleation processes in PA-6 and PA-12 matrices [45,46].

Further investigations revealed that FeO and Fe_3O_4-modified polyamide composites demonstrate improved wear resistance, dimensional stability, and thermal conductivity under conditions typical for mechanical engineering applications [46–48]. Comparative analyses with unfilled PA have shown a noticeable reduction in friction coefficients and surface degradation during tribological testing [50,51].

In addition, structural studies based on X-ray diffraction, electron microscopy, and infrared spectroscopy have demonstrated that the distribution and particle size of metal oxide fillers play a decisive role in determining the overall performance of the composite material [27,52–53]. Researchers also emphasize the importance of optimizing filler concentration and dispersion techniques to avoid agglomeration and ensure stable bonding with the polymer matrix [56].

Considering the ongoing demand for high-strength, thermally resistant, and lightweight engineering materials, the development of polyamide-based composites with controlled structural architecture remains an urgent task. Therefore, the structural diagnostics of PA-52 and its modifications with iron oxides is of both theoretical and practical importance and aligns with current research trends in materials science and mechanical engineering.

RESEARCH METHODS

The structural composition and phase characteristics of the polyamide-based composite with iron oxide nanoparticles were studied using a complex of instrumental analytical methods. The primary research techniques employed in this work were X-ray phase spectrometry and X-ray fluorescence (XRF) analysis.

To ensure high analytical precision and sensitivity, X-ray fluorescence analysis was conducted using the Rigaku NEX CG EDXRF Analyzer with Polarization (set – 9022 19 000 0)

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manufactured in Japan. The polarization technology of the instrument allowed for the reduction of background noise and the enhancement of detection accuracy of iron oxide inclusions at micro- and nanoscale levels. Both qualitative and quantitative elemental analyses were performed to determine the distribution and concentration of iron oxide nanoparticles within the polymer matrix.

X-ray phase spectrometry was applied to identify crystalline phases, investigate the degree of structural ordering, and analyze possible phase interactions between the polyamide matrix and the iron oxide nanoparticles. Special attention was paid to detecting changes in the polyamide crystalline regions, evaluating the dispersion state of nanoparticles, and assessing their influence on the supramolecular organization of the composite.

Sample preparation involved pressing and conditioning of specimens to ensure homogeneity and minimize geometric effects. Measurements were carried out under controlled environmental conditions to maintain reproducibility. The obtained spectra were processed using specialized software to interpret diffraction peaks, fluorescence emission lines, and phase composition profiles.

The combination of XRF and X-ray diffraction methods provided reliable insight into the microstructural features, phase interactions, and elemental distribution within the modified polyamide system.

RESULTS AND DISCUSSION

At the first stage of the work, in order to determine the elemental composition of polyamide-52 filled with iron oxides, the X-ray fluorescence method was used, the results of which are shown in Fig. 1.

The analysis made it possible to qualitatively and quantitatively identify the presence of iron-containing phases in the polymer matrix and to assess the uniformity of their distribution. Particular attention was paid to determining the concentration of FeO nanoparticles and their interaction zones within the structural network of the composite. The data obtained from XRF also served as a basis for comparing the modified material with the unfilled PA-52 sample in terms of elemental composition.

At the subsequent stages of the study, the structural features of the material were further examined using X-ray diffractometry in order to reveal possible phase transformations and structural ordering associated with the introduction of iron oxide nanoparticles. The combination of these two complementary methods provided a comprehensive understanding of the structural–elemental characteristics of the composite and confirmed the effectiveness of the chosen analytical approach.

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a

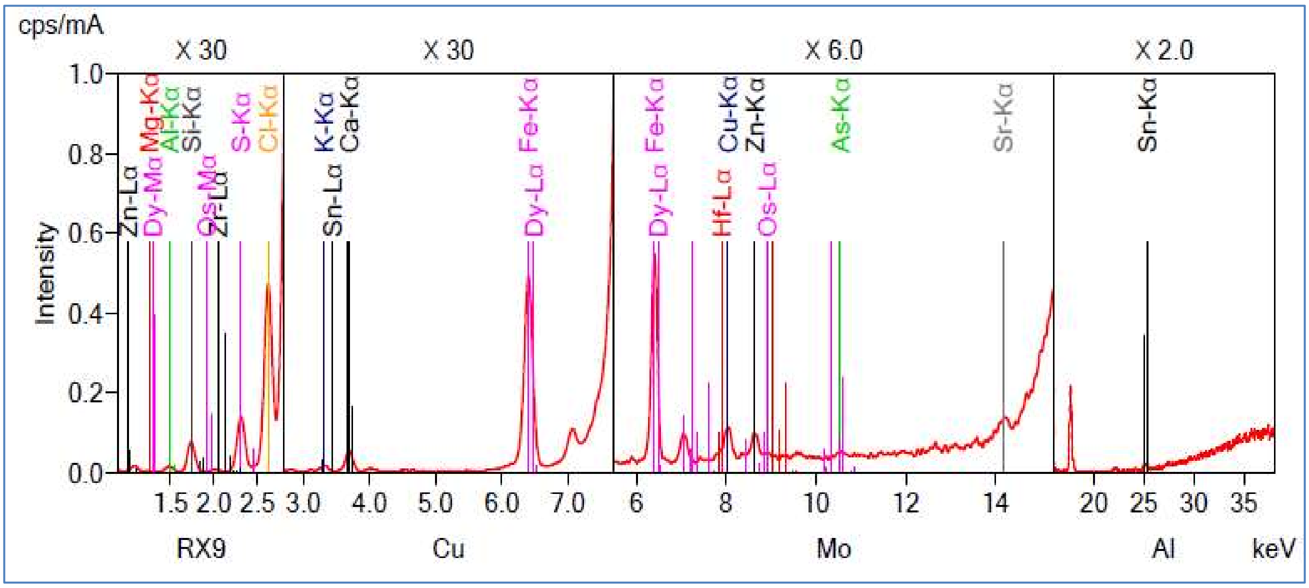

Fig. 1. X-ray fluorescence

b

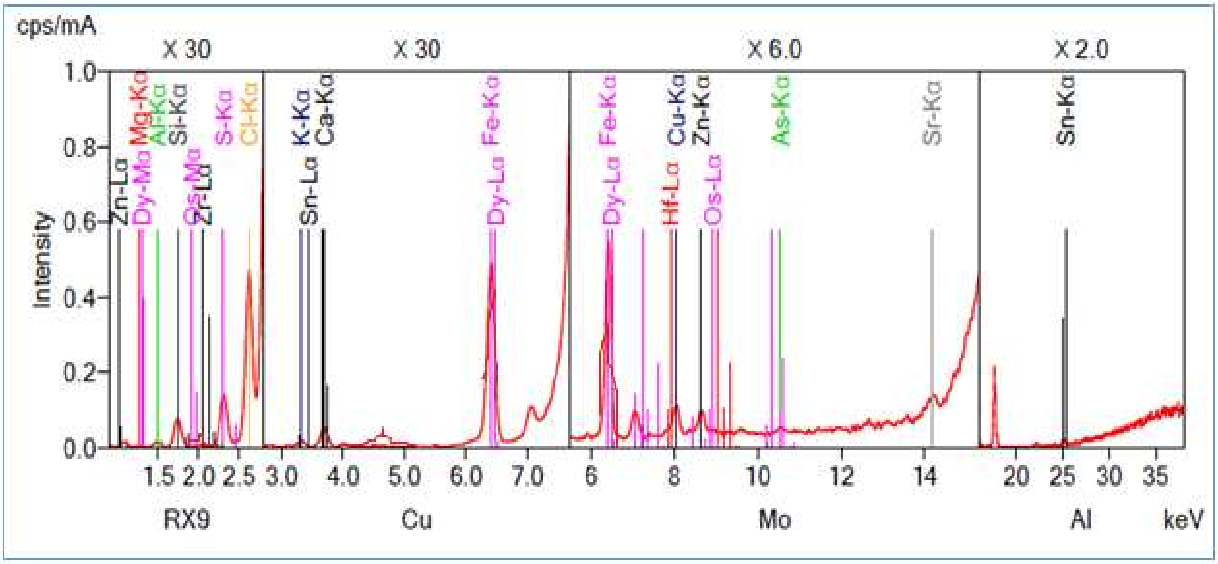

Fig. 1. X-ray fluorescence spectra of polyamide-52 (a) and polyamide-52 filled with FeO nanoparticles (b)

Elemental composition of composite compounds of polyamide-52 and polyamide-52 filled with FeO nanoparticles per 1 g of sample determined using The results of the method of fundamental parameters based on X-ray fluorescence analysis are shown in Tables 1 and 2.

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Analyzed result(FP method. Scatter)

No.	Component	Result	Unit	Stat. Err.	LLD	LLQ
1	Cl	0.0450	mass%	0.0003	0.0002	0.0006
2	Mg	0.0377	mass%	0.0041	0.0083	0.0248
3	Al	0.0441	mass%	0.0017	0.0017	0.0052
4	Si	0.0701	mass%	0.0012	0.0011	0.0033
5	S	0.0265	mass%	0.0003	0.0003	0.0009
6	K	0.0239	mass%	0.0012	0.0015	0.0045
7	Ca	0.0440	mass%	0.0011	0.0008	0.0024
8	Fe	0.0009	mass%	0.0005	0.0004	0.0012
9	Cu	0.0020	mass%	<0.0001	0.0001	0.0004
10	Zn	0.0013	mass%	<0.0001	<0.0001	0.0003
11	As	0.0002	mass%	<0.0001	<0.0001	0.0001
12	Sr	0.0002	mass%	<0.0001	<0.0001	0.0001
13	Zr	0.0609	mass%	0.0006	0.0001	0.0003
14	Sn	0.0006	mass%	<0.0001	0.0002	0.0005
15	Hf	0.0013	mass%	0.0001	0.0004	0.0011
16	Os	(0.0002)	mass%	<0.0001	0.0002	0.0006
17	Dy	0.0033	mass%	0.0004	0.0008	0.0025

Table-1

Analyzed result(FP method. Scatter)

No.	Component	Result	Unit	Stat. Err.	LLD	LLQ
1	Cl	0.0450	mass%	0.0003	0.0002	0.0006
2	MgO	0.0625	mass%	0.0068	0.0137	0.0410
3	Al2O3	0.0832	mass%	0.0032	0.0033	0.0099
4	SiO2	0.150	mass%	0.0026	0.0023	0.0070
5	SO3	0.0661	mass%	0.0007	0.0007	0.0022
6	K2O	0.0287	mass%	0.0014	0.0018	0.0054
7	CaO	0.0615	mass%	0.0016	0.0011	0.0034
8	FeO	0.0398	mass%	0.0007	0.0006	0.0017
9	CuO	0.0025	mass%	0.0001	0.0002	0.0005
10	ZnO	0.0016	mass%	<0.0001	0.0001	0.0003
11	As2O3	0.0003	mass%	<0.0001	<0.0001	0.0002
12	SrO	0.0003	mass%	<0.0001	<0.0001	0.0001
13	ZrO2	0.0821	mass%	0.0008	0.0002	0.0005
14	SnO2	0.0008	mass%	<0.0001	0.0002	0.0006
15	HfO2	0.0016	mass%	0.0002	0.0004	0.0012
16	OsO4	(0.0003)	mass%	0.0001	0.0003	0.0009
17	Dy2O3	0.0038	mass%	0.0004	0.0009	0.0028

It is known that in the composition of polyamide, along with iron oxides, non-metallic oxides and oxides of magnesium, vanadium, manganese, copper, germanium, zinc, tin and others are found in very small quantities [6,7,8,9,27, 32,35]. These results show that the introduction of iron oxide into polyamide exhibits its individuality. At the next stage, X-ray phase studies were carried out to identify the studied composite with known structural parameters and to compare the X-ray patterns obtained for polyamide -52 and polyamide with FeO nanoparticles [13,14,15,27, 38]. Table 3 shows the X-ray diffraction data for polyamide and polyamide + FeO.

Table -3: Radiographic information for composites

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No.	PA-52		PA-52+ FeO	
	D (Å)	I (%)	D (Å)	I (%)
1.	5.05	100	11.38	100
2.	4.48	20	6.45	42
3.	4.39	16	4.15	32
4.	4.21	17	3.99	46
5.	2.97	17	3.92	28
6.	2.52	22	3.89	28
7.	-	-	3.79	26
8.	-	-	3.72	26
9.	-	-	3.63	30
10.	-	-	3.53	18

Comparison of the results shows that these samples have their own individuality and in some percentage ratios differ significantly from each other. From the obtained X-ray patterns (Fig. 2) for comparison of interplanar distances and relative intensities for both samples, the maximum values of intensities in the spectrum were selected. Fig. 2 shows an X-ray pattern for polyamide and polyamide with iron oxide nanoparticles superimposed on each other.

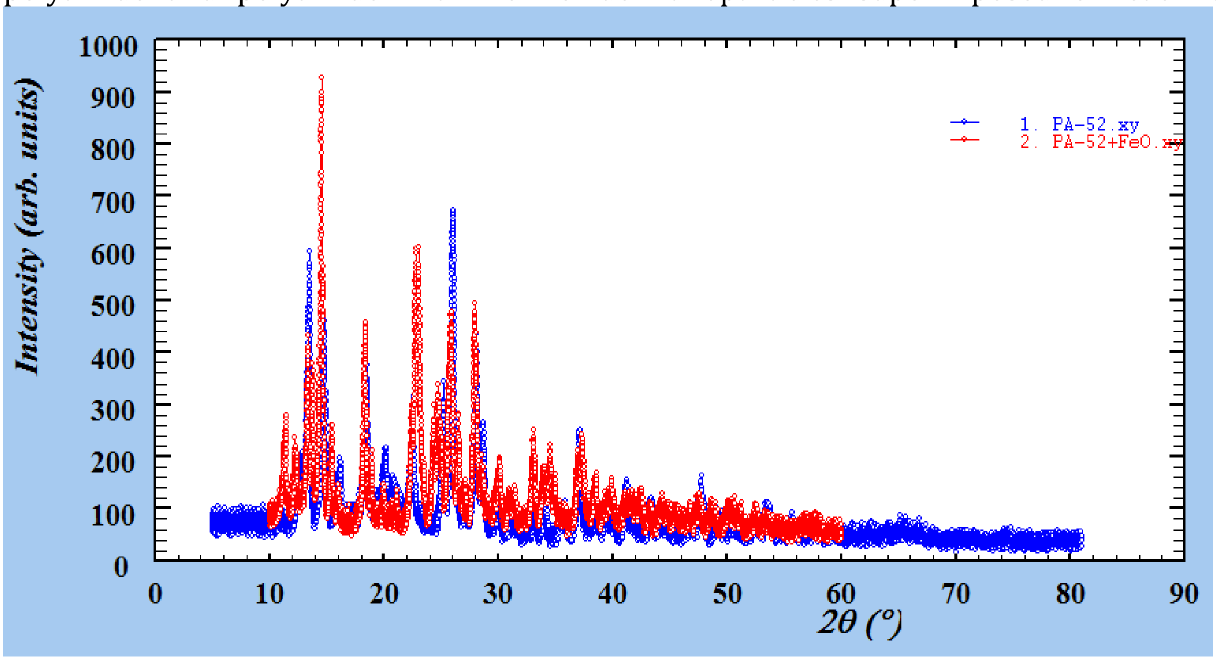

Fig. 2 X-ray images: PA-52 (1) and PA-52+ FeO (2)

Results of the study of radiographs for PA-52 and PA-52+ FeO show that they have a relative difference in structure formation. Structure formation of PA+ FeO occurs more pronounced .

CONCLUSION

-The presented results convincingly demonstrate the possibility and feasibility of using the X-ray fluorescence method to determine the structural composition of PA-52 and PA-52 + FeO composites.

-Method X-ray diffractometry has established the individuality of the substances of polyamide-based composites and their structure formation.

-The structural analysis carried out in this work confirms that the introduction of FeO nanoparticles into the PA-52 matrix can be controlled and evaluated with high accuracy using combined XRF and XRD techniques. This provides a reliable diagnostic approach for characterizing composite materials where inorganic fillers are integrated into polymer systems.

-The revealed structural features create a scientific basis for correlating the internal organization of composites with their functional characteristics, such as thermal resistance, mechanical strength, and wear performance. In particular, the absence of destructive changes in the crystalline lattice suggests that FeO-modified polyamide composites may retain or even improve their operational stability under external loads.

-From an application perspective, the studied materials show potential for use in mechanical engineering components exposed to friction, dynamic stress, or thermal cycling. The obtained data can aid in optimizing filler concentration, dispersion techniques, and processing parameters to improve the performance of engineering-grade polymer nanocomposites.

-Future research may focus on establishing direct relationships between the degree of structural modification and the tribological, rheological, or thermomechanical properties of the composites. It is also advisable to expand the analytical base through complementary methods such as DSC, SEM, FTIR spectroscopy, or thermogravimetric analysis to build a more comprehensive structure–property model.

-Ultimately, the findings of this study provide a solid methodological and experimental foundation for the rational design and development of next-generation polyamide-based nanocomposite materials with tailored performance characteristics.

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