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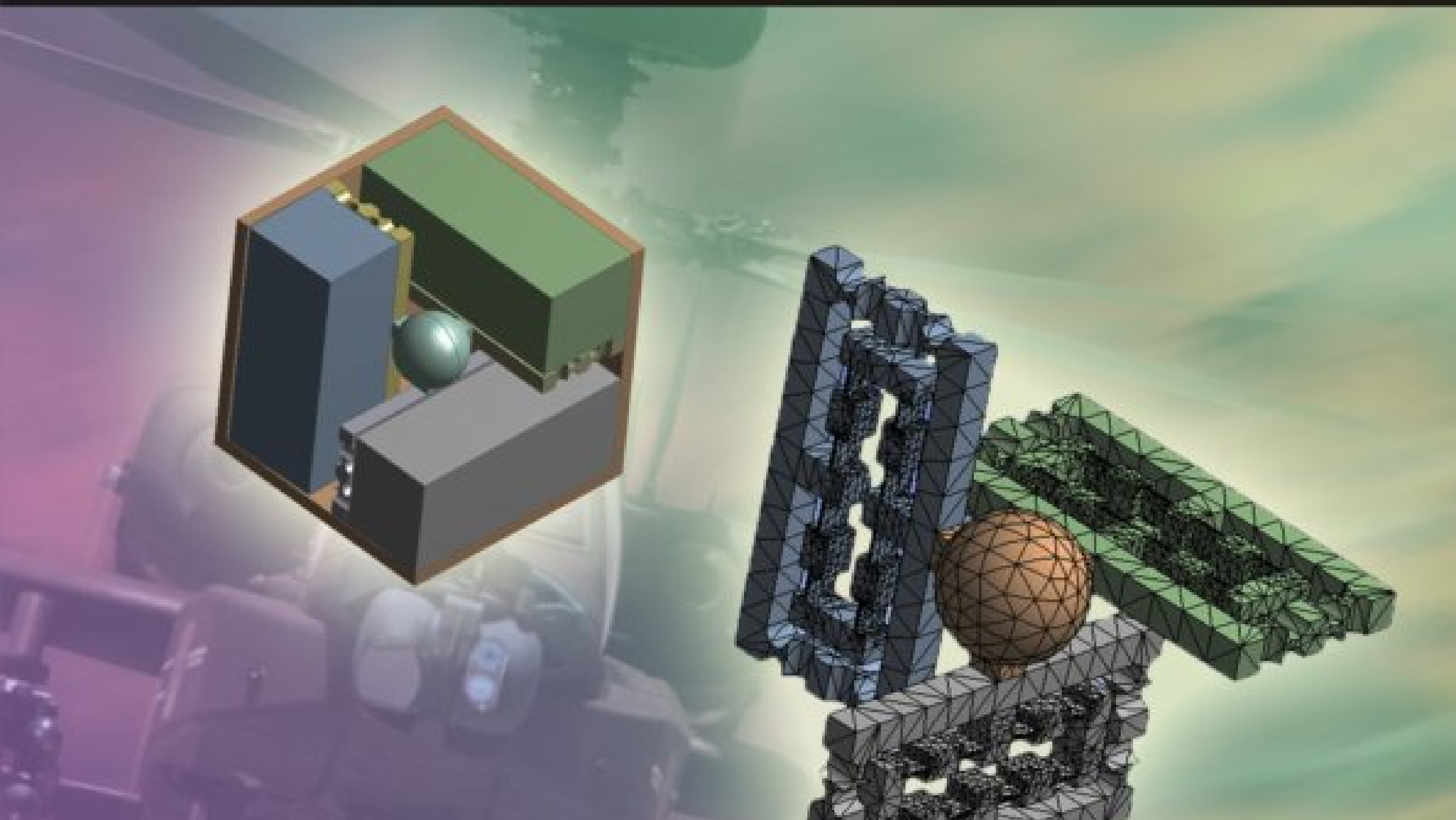

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Research Articles

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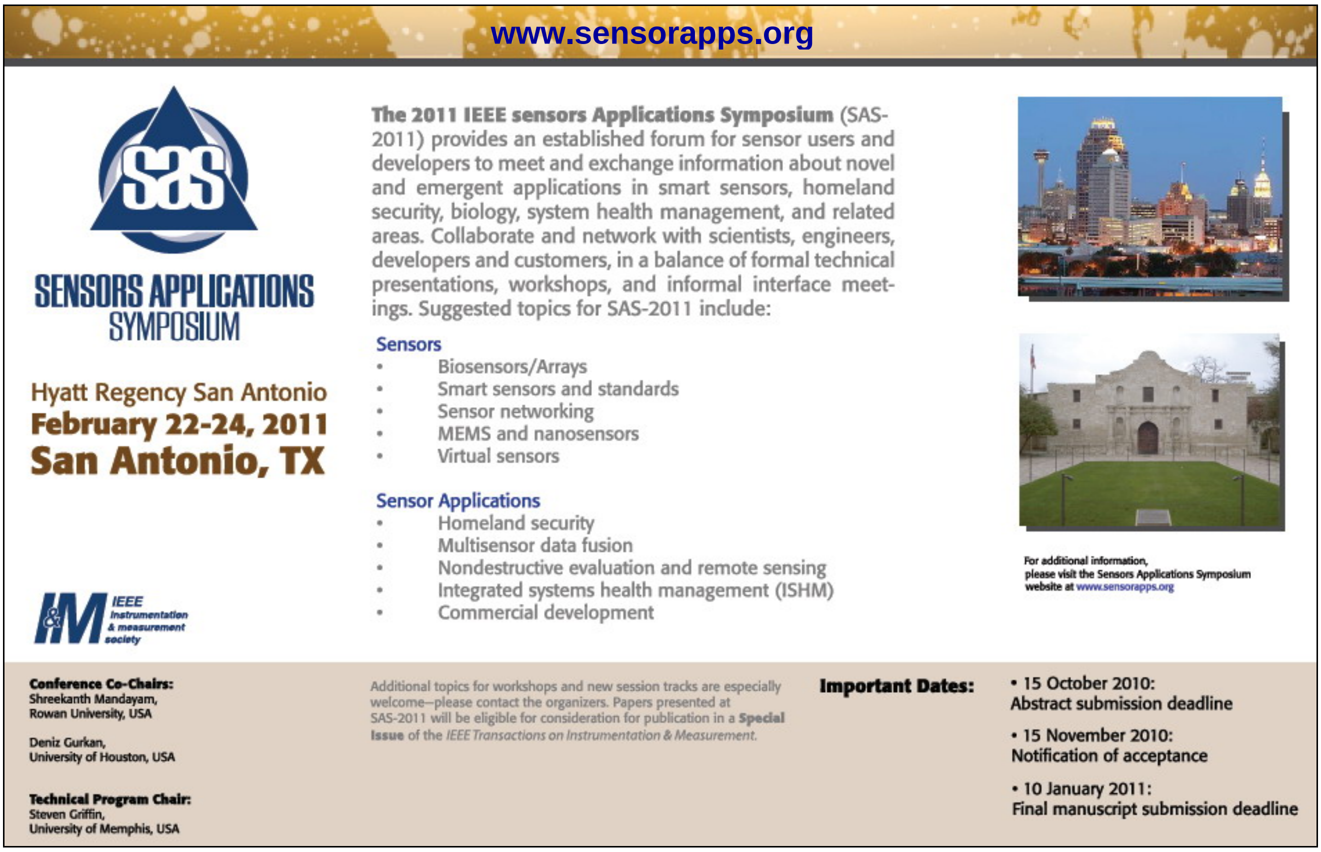

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The 2011 IEEE sensors Applications Symposium (SAS-2011) provides an established forum for sensor users and developers to meet and exchange information about novel and emergent applications in smart sensors, homeland security, biology, system health management, and related areas. Collaborate and network with scientists, engineers, developers and customers, in a balance of formal technical presentations, workshops, and informal interface meetings. Suggested topics for SAS-2011 include:

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Important Dates:
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Abstract submission deadline
- 15 November 2010:
Notification of acceptance
- 10 January 2011:
Final manuscript submission deadline

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on Sensor Device Technologies and Applications

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August 21-27, 2011 - French Riviera, France

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Submission deadline	March 23, 2011
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- Infrared
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- Sensors signal conditioning and interfacing circuits
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Tracks:
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- PESMOSN: Performance, simulation and modelling of sensor networks
- SEMOSN: Security and monitoring of sensor networks
- SECSED: Sensor circuits and sensor devices
- RIWISN: Radio issues in wireless sensor networks
- SAPSN: Software, applications and programming of sensor networks
- DAIPSN: Data allocation and information in sensor networks
- DISN: Deployments and implementations of sensor networks
- UNWAT: Under water sensors and systems
- ENOPT: Energy optimization in wireless sensor networks

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New Organic Solvent Free Three-Component Waterproof Epoxy-Polyamine Systems

[1]C. M. LACNJEVAC, [2]S. ZLATKOVIĆ, [3]S. CAKIĆ, [3]J. STAMENKOVIĆ, [1]M. B. RAJKOVIC, [3]*G. NIKOLIĆ and [1]S. JELIC

[1] Faculty of Agriculture, 11080 Belgrade-Zemun, St. Nemanjina 6, Serbia
[2] Actavis Trading Limited, Belgrade 11070, Serbia
[3] Faculty of Technology, 16000 Leskovac, Bulevar oslobodjenja 124, Serbia
E-mail: rajmi@agrif.bg.ac.rs, lcaja@agrif.bg.ac.rs, sjelic@agrif.bg.ac.rs
szlatkovic@info-net.co.rs, suzana_cakic@yahoo.com, goranchem_yu@yahoo.com

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Abstract: The unmodified GY epoxy resin (Vantico AG) was crosslinked by the aliphatic and cycloaliphatic EH polyamine adduct (Solutia-Vianova) in the different stoichiometric ratio. The optimal time of total crosslinking was determined by indirect measuring of the film hardness. The degree of the epoxy resin crosslinking and the quantity of unreacted epoxy groups have been monitored by the spectroscopic FT-IR method. The content and intensity changes of hydroxy group were correlated to the extent of epoxy reaction and crosslinking degree. By the parameters correlation and a period of resins application, optimal resin/hardeners stoichiometric ratio was defined. It was prerequisite for three-component epoxy system forming which is comparatively more elastic, adhesion and waterproof. *Copyright © 2010 IFSA.*

Keywords: Epoxy resin, Hardener, Polyamine adduct, IR spectroscopy.

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1. Introduction

The uncured resins may have a variety of physical forms ranging from low viscosity liquids to tack-free solids. As a result of this versatility, these products have found use in protective coatings, adhesives, body solders and caulking compounds, binders, inks, tooling compounds for moulds, sealants and encapsulant, textiles and fibre reinforced polymers [1, 2]. Epoxy resins are one of the most important and widely used types of polymeric systems. Epoxy resin systems have been used in a variety of applications including construction and building, automotive, aerospace, medical, electronics, offshore and engineering. The range of uses of epoxy resin systems includes adhesives, paints, sealants, inks, fillers, reinforced polymer composites and varnishes [3]. The epoxy systems are often used as binding materials in the production of the organic coatings. In practice, the systems take part in protection of the facilities exposed to the industrial atmosphere or the facilities in which drinking water, foodstuff, alcohol, organic solvents and other kinds of chemical products are stored or transported [4].

About 90 % of most of the different epoxy resins are made using diglycidyl ethers of bisphenol A (DGEBA) as the base resin [4]. The DGEBA is formed as a result of reaction between bisphenol A and epichlorhydrin (1-chloro-2,3-epoxy propane; δ-chloropropylene oxide), as shown in Fig. 1. These ethers represent the basic component of epoxy systems, when created from linear epoxy resins and the corresponding polyfunctional hardeners. The epoxide group is a three membered carbon, carbon, oxygen ring structure which is also known as oxirane group. The epoxy resin may contain one or more oxirane groups.

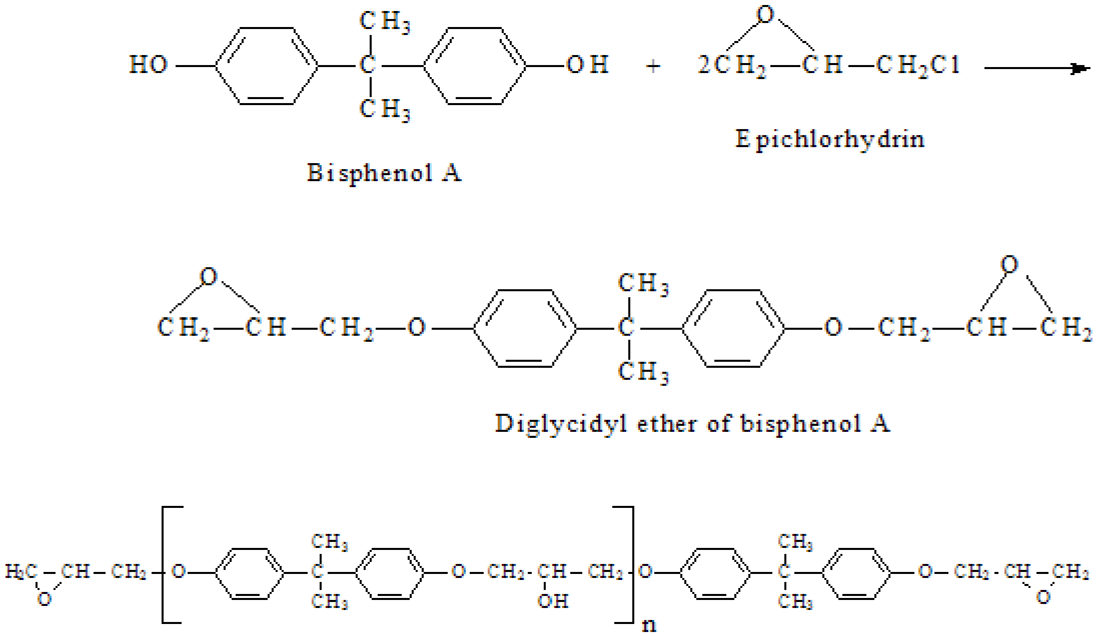

Fig. 1. The DGEBA formation as a result of reaction between bisphenol A and epichlorhydrin.

Epoxy resins cured with the aliphatic amines are extensively used in the protective coating applications. The new solvent free epoxy system in accordance with current health and ecological requirements has been investigated in this study. With new formulations of the solvent free coatings almost the same or even better properties can be obtained, which are in some aspects superior to the properties of the systems with solvent. The nature and the hardeners type for epoxy systems crosslinking significantly influence on the coatings characteristics [5]. The choice of a hardener and its structure variety enable creation of the systems according to wish. It results in a possibility to create the new waterproof systems of specific requirements and characteristics. We used two different polyamine adducts, aliphatic EH606 and cycloaliphatic EH637.

All chemical products, where is low molecular polymer transformed into a polymer of very high molecular mass and three-dimensional structure, are included in the epoxy resins crosslinking process [6]. Reactions that take place in the epoxy resins crosslinking process primarily refer to addition of hardener, through its functional groups, to the epoxy ring. The ratio of the functional groups essentially influences to the degree of crosslinking. The most optimal degree is achieved at the equivalent ratio of the functional groups that take part in the crosslinking process. In the organic solvent free coatings the epoxy molecules are crosslinked and completely in depth intertwined as well as on the surface.

The key to the performance of epoxy systems is in the epoxy/amine crosslinking reactions [7-9]. A simple crosslinking mechanism is shown in Fig. 2.

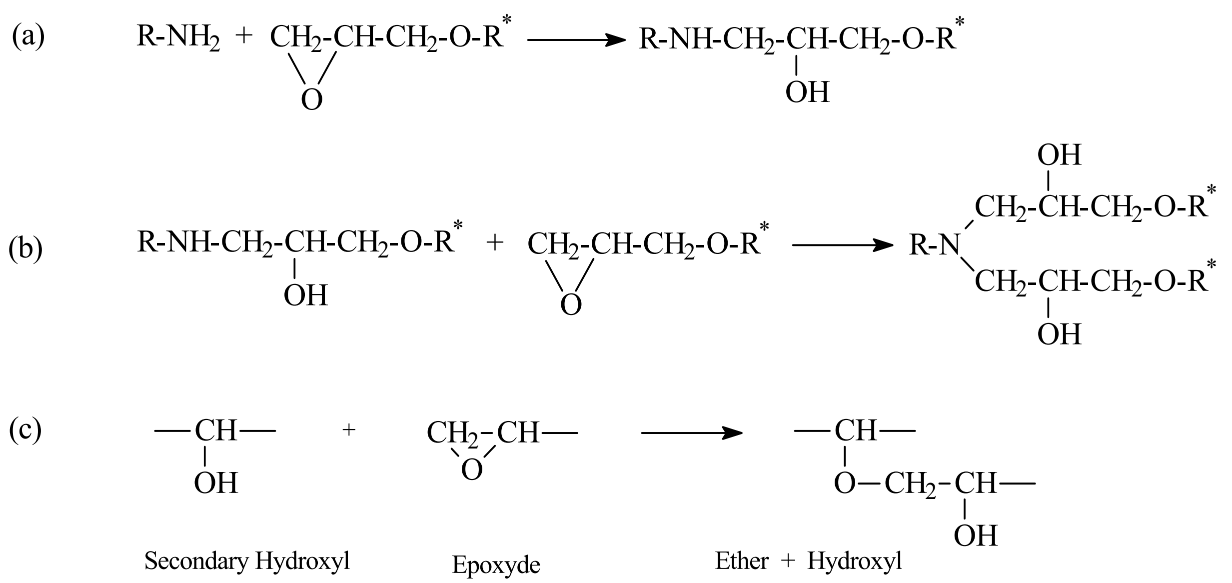

Fig. 2. The crosslinking reactions of epoxy resin with a primary (a) and secondary (b) polyamine, and etherification (c) in epoxy/amine reactions.

A primary polyamine can react with the epoxy as shown in Fig. 2a. Hydrogen atom from the primary amino group binds to the epoxy group and thus the three-membered ring of the epoxide opens, the epoxy group is converted to a hydroxyl group and the primary $–NH_2$ group is converted to a secondary =NH group. The resulting secondary amine can react with the epoxy ring (Fig. 2b). The secondary amino group reacts with another epoxy group thus producing a tertiary amino group and a hydroxyl group which originates from the epoxy group. The key to achieving low volume shrinkage are these ring opening reactions (unlike many other crosslinking reactions). The final reaction (Fig. 2c) illustrates that there still remains the potential for epoxy reaction between the –OH groups to further contribute to the development of a highly crosslinked coating [10].

Laboratory investigations demonstrated that these two reactions (Fig. 2a,b) show the same rate and accordingly it can be said that there is no difference in the reactivity between the primary and the secondary amino groups [11]. The reaction rate of the epoxy resins crosslinking with the polyamines depends on their chemical structure. Therefore, the aromatic polyamines crosslink the epoxy resins only at increased temperatures, while the crosslinking of the epoxy resins with the aliphatic polyamines can be also carried out at room temperature. This property is important especially from the point of view of surface protection of various materials. Therefore, the crosslinking without introducing heat has the priority. The type of chemistry involved in hardening the epoxy resins permits the user to cure over a wide range of temperatures. The temperature influence on the crosslinking is significant [12, 13]. At the temperature slightly below 15 ºC the crosslinking is significantly slowed down. At the temperature below 10 °C the process practically stops.

Depending on the chemical structure of the curing agent and the curing conditions, it is possible to obtain toughness, chemical resistance, mechanical properties ranging from extreme flexibility to high strength and hardness, high adhesive strength, good heat resistance and high electrical resistance. When it is necessary to provide the film coatings with better elasticity, adhesivity and water resistance, the cycloaliphatic polyamines are also used as hardeners due to their characteristic structure.

Therefore, the aim of this paper is formation of three-component epoxy system with better elasticity, adhesivity and water resistance, by introduction of aliphatic polyamine and cycloaliphatic polyamine as the hardeners. These systems are chosen for many reasons, including the excellent chemical resistance achieved from a crosslinked coating film and excellent adhesion to various substrates due to low volume shrinkage during cure. By monitoring the increase of the hardness of the formed film and FT-IR spectroscopic identification of functional groups which have reacted mutually, the time of total crosslinking and the quantitative ratio of the reacted and the unreacted epoxy groups in the system can be defined [14]. The effect of the amine groups on the epoxy groups was investigated by mid-IR techniques for its effect on crosslinking kinetics. By correlation of these parameters that directly depend on the crosslinking degree, it is expected to obtain the epoxy systems which will be considerably more suitable for practical application.

2. Experimental

The epoxy resin crosslinking was carried out at room temperature [11]. The specified quantities of unmodified epoxy resin GY250 (Vantico AG, Switzerland), hardeners EH606 and EH637 (Solutia-Vianova, Austria) were subjected to mixing in different stoichiometric ratio (100:22:28, 100:23:27, 100:24:26 and 100:25:25, respectively). The obtained mixture was applied to a hard base. The films were formed at the ambient temperature by the reaction of polyaddition [15].

The hardness of the dry film was determined indirectly [16], by measuring the time during which the oscillating amplitude of the specified pendulum lying on the film was reduced.

The epoxy resin crosslinking with the chosen hardeners was monitored by FT-IR spectroscopy [17]. The IR spectra of the basic epoxy resin and the hardeners were recorded by a method of applying thin layer (0.2 mm) on the carrier KBr plates. The IR spectra of the crosslinked resins were recorded by means of the KBr technique [18]. The background spectrum was renewed after each sample spectra. The recordings were carried out on the Bomem Hartmann & Braun MB-100 FT-IR spectroscope, in the spectral range of 4000-400 cm^{-1}, using 20 scans and 2 cm^{-1} resolution. The measurement time for each spectrum was about 20 sec. Spectra were manipulated and plotted with the use Win-Bomem & Easy software package. The software was used to determine the characteristic IR bands area [19]. Validation of the IR test results was carried out by a chemical method [20].

3. Results and Discussion

To make a crosslinked epoxy resin with good characteristics and determine its optimal application time are the important factors for the practical use in foodmaking, pharmaceutical and other branches of chemical industry. To determine the chemical groups which participate in the reaction, to clarify the mechanism and kinetics of the reaction, to quantitatively express the content of the unreacted groups, these are the questions of scientific contribution which lead to improvement of the existing applicable systems. Each stoichiometric ratio will give different quantitative ratio of the reacting epoxy group.

The epoxy resin GY250, unmodified viscous resin based on bisphenol A, which makes it very suitable for applications in environments and reactions with increased temperature, was used in the investigations. The technical characteristics of the epoxy resin were determined and presented in

Table 1. Due to characteristic viscosity in the range from 9000 to 12000 mPas, with flash point higher than 200 ºC, it is exceptionally suitable for making coatings for protection of the facilities exposed to industrial athmosphere, as well as for the protection of the facilities in which foodstuff and drinking water are stored or transported. Having in mind that the crosslinked epoxy system can be created by choice of appropriate hardeners, the following hardeners have been chosen for further investigations: EH606 (aliphatic polyamine adduct) and EH637 (cycloaliphatic polyamine adduct). The characteristic parameters of the amine hardeners used in all studies are summarized in Table 1.

Table 1. Physical and chemical parameters of the epoxy resin GY250 and the applied EH hardeners.

Mark	Composition	η_{25} (mPas)	Epoxy number (Eq/g)	Equivalent (g/Eq)	*C* (%)	Flash point (ºC)
GY250	Unmodified medium viscous epoxy resin based on bisphenol A	9000-12000	5.3-5.45	Epoxy 183-189	100	≥ 200
EH606	Aliphatic polyamine adduct	3000-4000	-	H-activ. 100	100	≥ 200
EH637	Cycloaliphatic polyamine adduct	90-120	-	H-activ. 100	100	≥ 105

3.1. The Crosslinking Analysis

In the series of experimental investigations, the stoichiometric ratio optimization of the hardeners and the epoxy resin was carried out (Fig. 3). On the basis of the shortest hardening time, EH606/EH637 = 25:25 was chosen as the most optimal stoichiometric ratio between the hardeners, that is, the epoxy system 4S (GY250/EH606/EH637 = 100:25:25). The change of film hardness of the picked 4S system in relation to days of crosslinking is shown in Table 2.

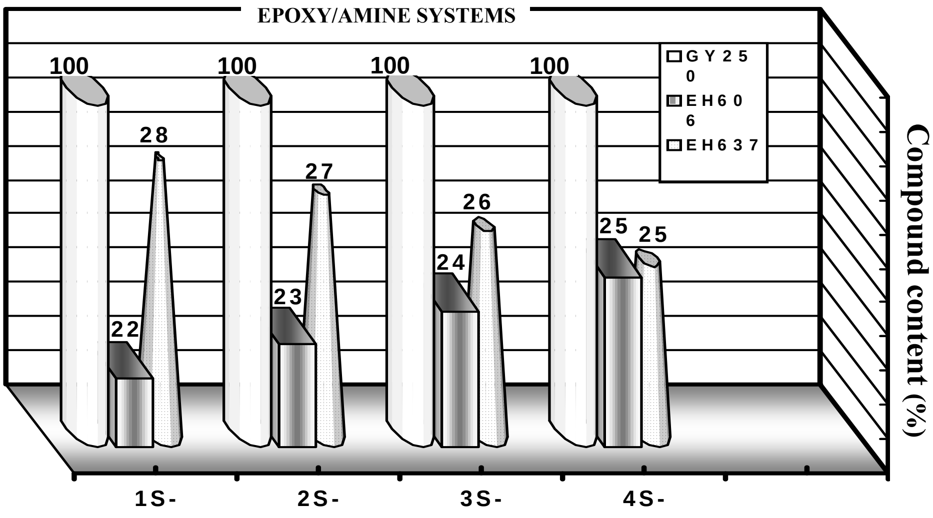

Fig. 3. Comparison of epoxy/amine systems (1S, 2S, 3S, 4S) according to the GY250/EH606/EH637 stoichiometric ratio.

Table 2. Change of film hardness by crosslinking of the epoxy 4S system.

Days	1	2	3	6	8	9	10
Hardness (sec Kö)	94	116	125	140	139	140	140

By analysis of the obtained results it can be observed that the constant value of the hardness degree is achieved in the period from the 6th to the 10th days, which points out that the crosslinking process is completed in the system after the 6th days. After 3 days of crosslinking, the catalytic action of tertiary amines was observed, and that the crosslinking process accelerates by the increase in concentration of the hydroxyl groups [21].

3.2. FT-IR Spectra Assignation

FT-IR spectrum of the epoxy resin GY250 is shown in Fig. 4 a.

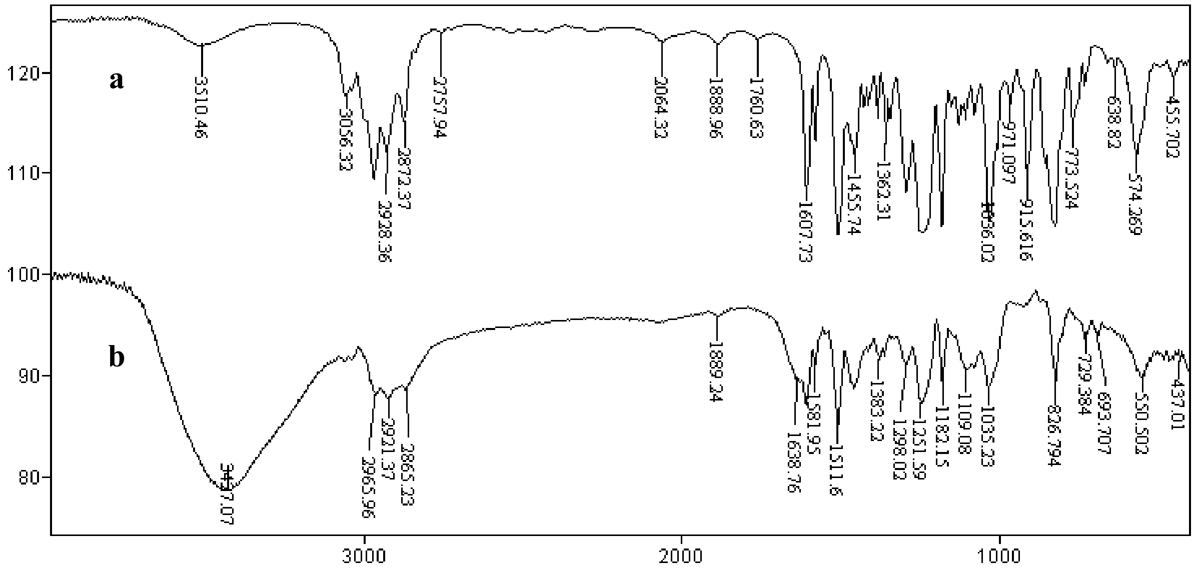

Fig. 4. FT-IR spectra of the unmodified GY250 (a), and the crosslinked 4S (b) epoxy resin.

The characteristic epoxy group can be assigned [22] by the following IR bands: 3056 cm^{-1} from the valent CH vibrations of the epoxy ring, 1036 cm^{-1} from the valent CO vibrations of the epoxy ring, and 915 cm^{-1} from the bending CH vibrations of the epoxy ring. The band at 3510 cm^{-1} point out to the presence of weakly associated OH group and it originates from the stretching OH vibration. It is confirmed by the bending vibration in the plane δ(OH) at about 1415 cm^{-1} and the vibration off the plane γ(OH) at about 570 cm^{-1}. The band at about 3036 cm^{-1} it originates from the stretching CH vibration of the aromatic ring. Benzene ring in the IR spectrum is characterized by the bands of the skeleton vibrations at 1607 cm^{-1}, 1581 cm^{-1}, 1510 cm^{-1} and 1455 cm^{-1}. Overtones in the range 2000-1600 cm^{-1} as well as the intense peak at 830 cm^{-1} point to 1,4-disubstitution of the benzene ring. The absorption maxima at 2967 cm^{-1} and 2872 cm^{-1} characterize the asymmetric ν_{as}(CH) and symmetric ν_s(CH) stretching vibration from CH_3 group. The band at 2928 cm^{-1} originates from the asymmetric ν_{as}(CH) vibration of CH_2 group, whose partner is in the bending area of the plane at about 730 cm^{-1}. The alkyl groups should be pointed out that in this case the methyl group in the molecule is in $–C(CH_3)_2$ form, as shown by the bands at 1384 (weaker ones) and at 1362 cm^{-1} (stronger ones) which originate from the deforming δCH vibration in the plane, whose partner is at 1184 cm^{-1}. Relatively wide and intense band at about 1247 cm^{-1} represents a combination of ν(CO), δ(OH) and ν(COC) vibrations, and so it is characteristic of the presence of the epoxy, hydroxyl and ether $C_{ar}–O–C_{al}$ groups, respectively. The symmetric valent vibration of the ether group produces a band at 1036 cm^{-1}.

The hardener EH606 is an polyamine adduct and contains the primary and the secondary amino groups, as confirmed by the presence of the complex IR band in the range 3100-3400 cm^{-1}. The peaks at 3345, 3280 and 3175 cm-1 originate from the stretching ν(NH) vibration from NH_2 i NH group. The peak at 1458 cm^{-1} is characteristic for the aliphatic amines. Doublet in the deforming IR range at 1374 and 1346 cm^{-1} points to the presence of δ(CH) vibration from $–N(CH_3)_2$ group in the molecule. The peak at 1109 cm^{-1} originates from CN stretching vibration. The other bands are assigned similarly to the previous spectrum.

The hardener EH637 is a cycloaliphatic polyamine adduct. The complex IR band with the peaks at about 3343, 3280 and 3176 cm^{-1} originates from the valent ν(NH) vibrations from NH_2 and NH groups. The complex band in the range 3000-2800 cm^{-1} is a results of the CH coupling vibrations. The bands in the range of 3100-3000 cm^{-1} originate from the valent vibrations of the cycloaliphatic CH groups. The band with the doublet at 1385 and 1364 cm^{-1} originates from the bending vibrations of $N(CH_3)_2$ groups. The characteristic bands at 735 i 698 cm^{-1} originating from the bending CH vibration confirm that it is monosubstituted cycloaliphatic compound.

3.3. Crosslinking Characterization by IR Spectroscopy

The epoxy resin may contain one or more oxirane groups. The ability of this group to undergo a large variety of polymerization and crosslinking reactions leads to many different types of epoxy resins with a wide range of commercial and physical properties. FT-IR spectrum of the crosslinked 4S system is shown in Fig. 4b.

For the purpose of comparison and easier noticing of qualitative changes which occur during the crosslinking, the Fig. 4a shows also the FT-IR spectrum of the unmodified starting epoxy GY250 resin. By detailed analysis of the FT-IR spectra significant changes can be observed. First, in the stretching and the bending area of –OH and –NH groups. Second, in the epoxy groups area. These observations point out that the amino groups of the hardeners and the epoxy groups of the resin participate in the process of crosslinking. Thus, besides assignation of IR bands, special attention should be paid to the quantity of the groups which participate in the process.

As is known [12], the mechanism of epoxy resin crosslinking is represented by the reaction of epoxy group with the primary or the secondary amino group (Fig. 2). Transformation of the primary and the secondary to the tertiary amino group can be confirmed by reducing the intensity and loosing of the band in the area of the valent ν(NH) vibrations (3344 and 3285 cm^{-1}). The simultaneous appearance of wide and intense band at about 3430 cm^{-1} from the valent ν(OH) vibration, the change of shape and intensity point to the increased content of OH groups during the crosslinking. This fact is confirmed by the appearance of the band at about 1638 cm^{-1} in the crosslinked 4S system, which originates from the bending OH vibration. Moving of the band position from the ν(OH) vibrations toward lower frequencies for about 80 cm^{-1} in the crosslinked resin (Fig. 4b), in comparison with the unmodified resin, point to the forming of stronger hydrogen bonds.

Reducing of the intensity and almost disappearing of the IR band at 3056 cm^{-1} characterize the opening of the epoxy ring, its reactivity and change of the content. This fact gives a possibility of quantitative determination of the reacting epoxy groups during the crosslinking, that is, of the resin crosslinking degree. In favor of this speaks the change in the intensity of the bands in the range from 1450-1300 cm^{-1} from δ(OH) and δ(CH) vibrations, in the range from 1150-1050 cm^{-1} from ν(CO) and ν(CC) vibrations, as well as in the range from 960-850 cm^{-1} from γ(CH) vibration. The corresponding partners of the vibrations in the bending range of the epoxy groups due to overlapping with the vibrations of other groups exclude the possibility of monitoring the content change in this range. In the FT-IR spectrum of the crosslinked resin (Fig. 4b), the position and the shape of the other bands remain unchanged.

3.4. Epoxy Group Content

Mid IR spectroscopy has been extensively used to monitor cure reactions of epoxy/amine [23-27] and other resins [28]. Namely, the crosslinking takes place by opening of the epoxy ring of the resin with the active hydrogen from the amino group of the hardener, with forming of the hydroxyl group. It is confirmed by intensity reduction of the CH bands at 3056 cm^{-1} and 915 cm^{-1}, as well as appearance of OH group band at 3430 cm^{-1}. However, the mid IR spectra in epoxy/amine systems is very complex, with the epoxy peak at 915 cm^{-1} difficult to follow as described by several authors [29-31].

The fact is that functional groups of the epoxy resin involved in the crosslinking reactions are hydroxyls. For DGEBA, it has been known that the cure reactions can be promoted with catalysis effects of –OH group. The reactivity of the hydroxyl groups along the polymer chain can be expected to be different. In particular, based upon the steric consideration, the most reactive would be the OH lateral group, then the end-chain OH group and then the mid-chain OH group.

Having in mind that the addition of hydrogen atom to the epoxy ring produces polar hydroxyl groups, as well as the secondary amino groups, the increase of the intensity of ν(OH) band in IR spectra at about 3430 cm^{-1} is expected during the crosslinking of the resin. Fig. 5 shows the partial FT-IR spectra for the epoxide and the hydroxyl group of 4S system during crosslinking process. The hydrogen bonding is apparent in 4S systems. The characteristic moving of the absorption maxima of the described band toward the higher frequencies can be observed from the same spectra. Namely, as the process of crosslinking proceeds to the tertiary amines with their distinct catalytic action, and the increase in concentration of the hydroxyl groups accelerates the crosslinking process, this change of the position of ν_{OH} band can be explained by the reduced possibility of establishing the hydrogen bonds.

The amino groups in the IR spectra of the crosslinked epoxy resin have not been identified (Fig. 4b and 5), which can be interpreted by satisfactory participation of the hardener quantity in the formulation. In this system, a part of the epoxy groups remained free, not only due to intense increase in viscosity but also due to the way of formulating (stoichiometric ratio of the functional groups), but by such formulating satisfactory elasticity is achieved.

In order to establish exactly the quantitative change of the epoxy group in the crosslinked system 4S, a calibrating diagram of the epoxy group content (from epichlorhydrin) against the area of the characteristic IR band of the epoxy group was constructed (Fig. 6).

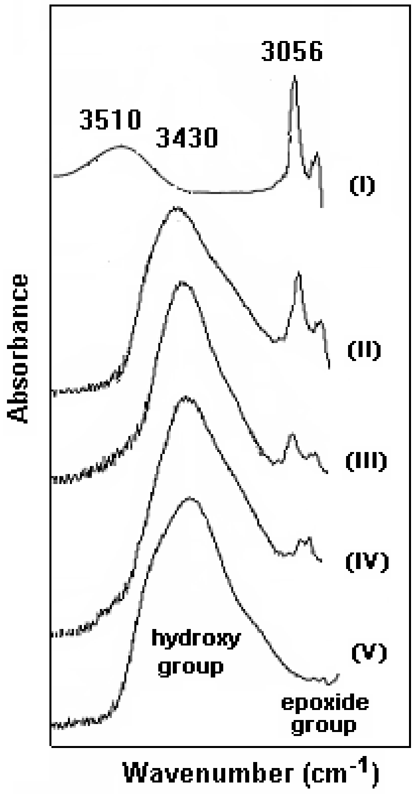

Fig. 5. The partial FT-IR spectra of the unmodified GY250 resin (I) and the crosslinked epoxy 4S system after: 1 (II), 3 (III), 5 (IV) and 7 (V) days.

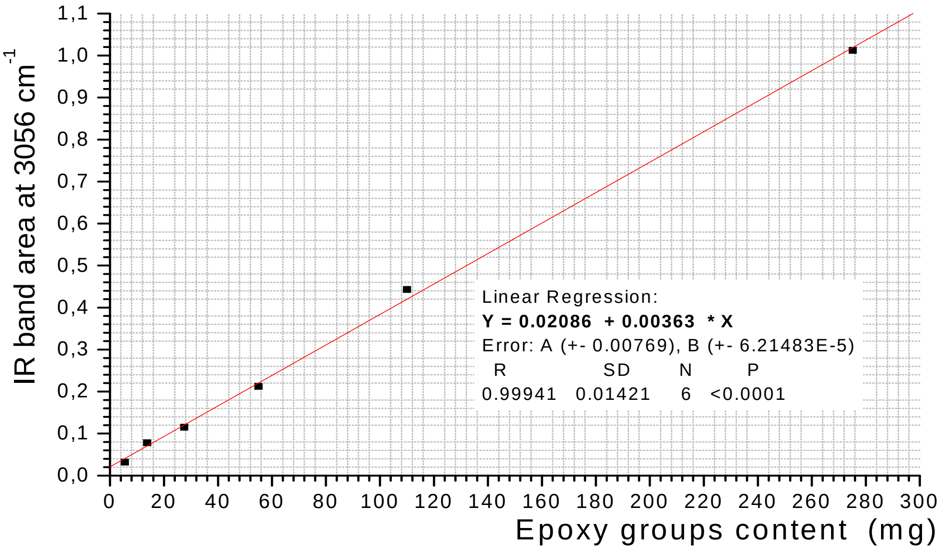

Fig. 6. Calibration diagram of the epoxy groups content in the function of the IR band area at 3056 cm^{-1}

Reading of the total band area made of two absorption maxima in the range 3080-3020 cm^{-1} from the IR spectra of the crosslinked system 4S (Fig. 5), was carried out by use of the original Win-Bomem & Easy software [19]. As this band is formed by overlapping of the peaks of the reacting epoxy group (ν_{CH} at 3056 cm^{-1}) and the unsaturated aromatic ring (ν_{CH} at 3038 cm^{-1}), it was not possible to carry out the precise separation. Having in mind that content of the aromatic groups does not change during the crosslinking, share of the area of the epoxy group (P1, Fig. 7) was determined by mathematical method of square covering [32], where the percentage share of individual peaks in relation to the total area of the IR band is calculated.

For each spectrum, the ratio of the peak area of the O–H stretching band (3680-3030 cm^{-1}) and epoxy CH_2-O-CH- group stretching band (attributable to system, 3056 cm^{-1}) to the standard epoxy group band (attributable to epichlorhydrin) was calculated. The areas change of the IR peak, which corresponds to the content of the unreacted epoxy group, is shown in Fig. 8 as function of crosslinking time. From the IR band area (Fig. 8), by the calibrating diagram (Fig. 6), the remaining epoxy groups content was determined in the crosslinking process of the 4S system, which represents the measure of the resin crosslinking degree (Tab. 3). On the basis of the unreacted epoxy group content in the crosslinking being 17.1 mg in mass of epoxy resin of 2.0 g, the maximum crosslinking degree of 93.4 % after 6 days for the given stoichiometric ratio 100:25:25 (GY250:EH606:EH637) was determined.

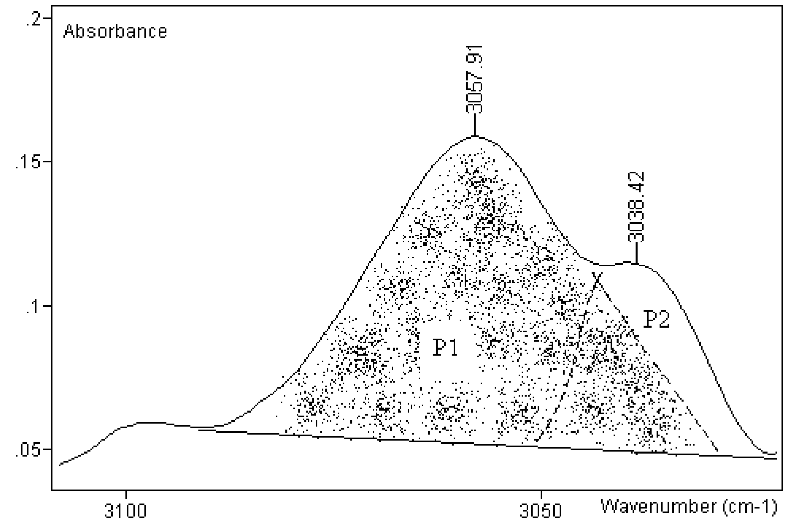

Fig. 7. Partial IR spectrum of the GY250 resin in the valent CH range 3100-3000 cm^{-1}. The hatched area P1 represents the epoxy group peak and P2 represents the aromatic ring peak.

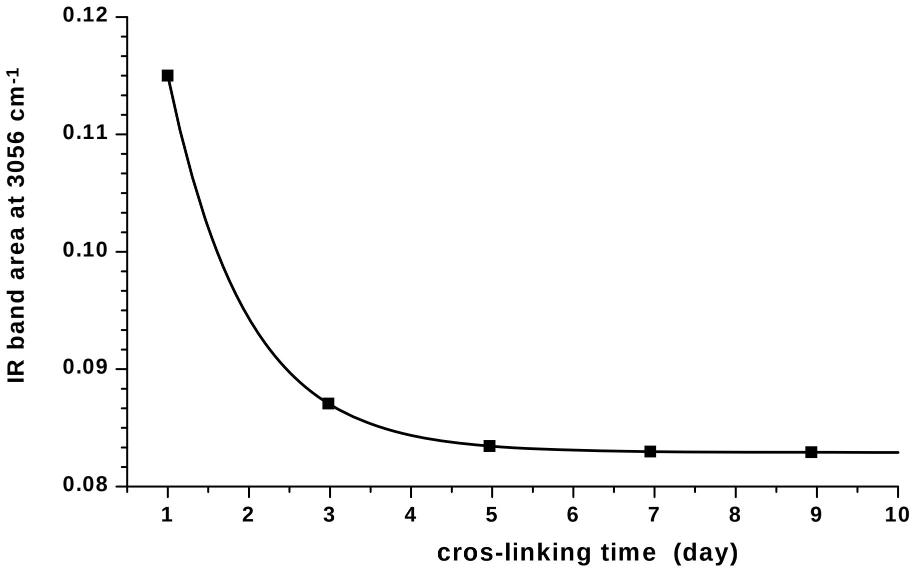

Fig. 8. The change of IR band area at 3056 cm^{-1} from the epoxy group during crosslinking process of the 4S system (GY250/EH606/EH637 100:25:25 stoichiometric ratio).

Validity of the developed FT-IR method was checked by the standard chemical method for epoxy group content determination, that is, the epoxy equivalent [20]. By comparison of the epoxy groups content obtained by the chemical and spectroscopic method (Table 3), the exceptionally good agreement of the results with the error being < 3 % can be observed.

Table 3. Epoxy group content and crosslinking degree of the epoxy 4S system.

Time (days)	0	1	3	6	10
Epoxy group content, by the chemical method (mg)	260.4	25.2	18.6	17.9	17.4
Epoxy group content, by the IR spectroscopic method (mg)	259.8	25.9	18.2	17.1	17.1
Resin crosslinking degree, by the IR spectroscopic method (%)	0	90.1	93.0	93.4	93.4

By comparison of the film hardness results (Table 2) with the crosslinking degree results (Table 3), it can be observed that the crosslinking in both cases achieves saturation in the period from the 3rd to the 6th day of investigation, and is completed after the 6th day. It is considered that after this period the crosslinking of the epoxy 4S system is finished and the crosslinked resin can be used for the planned purpose.

The developed IR spectroscopic method can be applied in other epoxy systems of different stoichiometric ratio for determination of the crosslinking degree, that is, the content of the epoxy group [33]. The limiting factor in the application of this method can be the quality of the obtained FT-IR spectrum of the system being investigated which to a greatest extent depends on the method and technique of the sample preparation for the spectroscopic analysis.

4. Conclusion

By indirect measuring of the film hardness, the optimal stoichiometric ratio of the used components was determined to be 100:25:25 (GY250:EH606:EH637) in the process of three component epoxy 4S system forming. The optimal time for total crosslinking of the epoxy system is 6 days, after which the system can be practically applied.

The FT-IR spectroscopy proved to be a good method for monitoring and assigning characteristic changes which occur during the epoxy systems crosslinking.

The method of FT-IR spectroscopy was developed to the crosslinking degree determination of epoxy resin and the quantity of the unreacted epoxy groups. With this method the results are obtained with the error of < 3 %, in comparison with the standard chemical method.

On the basis of the unreacted epoxy group content in the crosslinking being 17.1 mg in the epoxy resin mass, the maximum crosslinking degree of 93.4 % was determined after 6 days for given stoichiometric ratio of 100:25:25.

By correlation of FT-IR spectra and parameters which directly depend on the crosslinking degree, as well as the time of applicability of the epoxy resin, the optimal stoichiometric ratio of the components can be defined, as a prerequisite for the forming of three-component epoxy system of relatively higher elasticity, adhesivity and water resistance.

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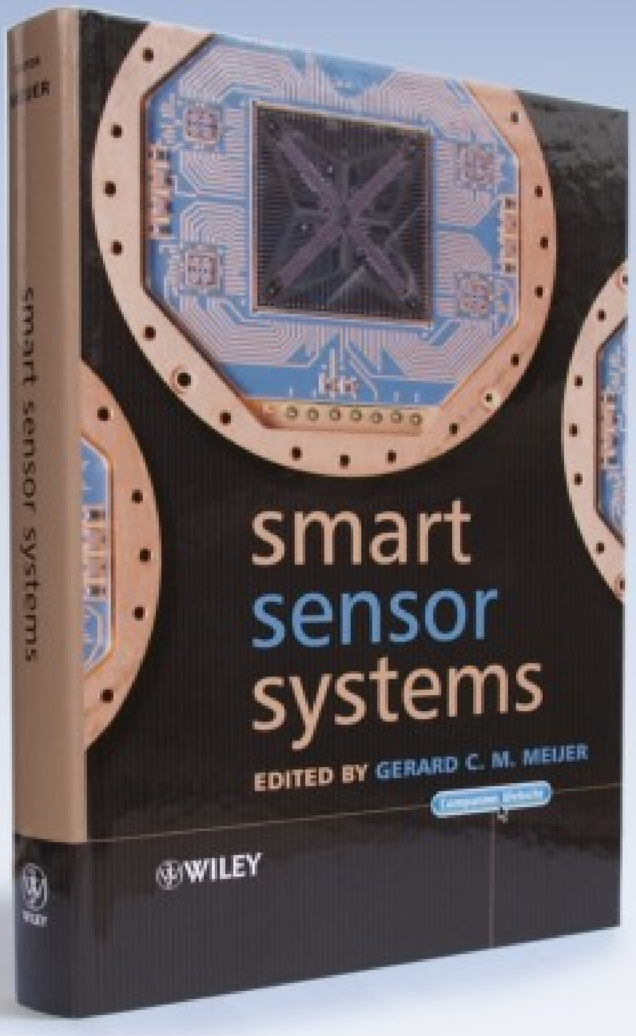
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