Radiographic Industrial Films Used for Non-Destructive Testing (NDT)

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Abstract. This paper is the first experience of systematization of X-ray sensitometric and structuremetric characteristics, as well as surface silver concentration and the emulsion layers thickness of radiographic industrial films manufactured by photochemical companies all over the world. All films have been divided into several classes, in accordance with the Standard recommended in Russia named "Nondestructive Radiographic Testing Method".

To start with, it should be mentioned that at present in Russia there is no single standard for classifying radiographic films, methods of their testing, as well as the standard regulating the use of chemicals for radiographic films photoprocessing that corresponds to European Standard [1]. In the 1980-s the information became available relating to new methods of image quality estimating for radiographic films used in NDT (nondestructive testing) depending on the quality of the films, as well as information concerning film classification methods. In accordance with up-to-date standards, the quality of radiographic films is usually divided into 4 or 6 classes [1,2,3,4-6]. The most important criteria of radiographic films quality for NDT are **graininess** (noise), **gradient** (signal) and **detection quantum efficiency** (DQE), that is, the ratio signal/noise of the radiation flow (exposure) hitting on the film to the ratio signal/noise of the radiation absorbed by the emulsion layer (the image on the film). In this case the information capacity of radiographic film takes into consideration the properties of the emulsion layer itself. So DQE enables to compare different radiographic films with reference to the object of radiographic testing. The high gradient (contrast) of radiographic film (defined as signal) also contributes to increasing its information capacity. Thus, the most important criteria of radiographic films information capacity in all classification systems are the amounts of gradient (**G**) and graininess (**σ**). It was on the basis of these criteria that International and European Standards for radiographic films classification were developed and accepted in 1994-1997 [6-12]. Considering the range of radiographic films manufactured in Russia, the most reasonable classification for our country [see1,2] uses division into 4 classes according to the following characteristics: radiation sensitivity, reflectance ratio and gradient.

The main objective of this paper is to systematize all information concerning the classification of radiographic films recommended for Russia [2], to carry out the comparative analysis of different films produced by companies all over the world, taking into consideration their sensitometric and structuremetric characteristics as well as the surface silver concentration in emulsion layers. Such kind of information is being submitted for the first time, and all data are based upon the results of testing radiographical materials produced both in Russia and other countries.

Before we give an account of the results of radiographic materials tests, we will agree upon some common terms: by sensitivity class of radiographic testing we mean the requirements for the radiographic testing sensitivity determined by the formal documents containing designers regulations concerning the object tested [2]; by radiographic film class the authors of the Russian draft mean the combination of the required X-ray sensitometric characteristics of a film that can provide a radiographic image of the corresponding class [2]; radiographic film sensitivity (**S**) is usually interpreted as a value that is reverse to the exposure dose (**H**) (that is, radiation dose) which is necessary for obtaining optical density that is accepted as a sensitivity criterion: $\mathbf{S}_{кр} = 1/H_{(D\ кр)}$. According to Russian regulations, the following criterion values are accepted: $0{,}85 + D_0$ [14] and $2{,}0 + D_0$. [2,14]. The unit of radiation sensitivity in International and European Standards is Gray. In Russia radiation sensitivity is measured in inverse Roentgens ($\mathbf{P}^{-1}$). In the draft Standard considered in this paper we are using **kg/Kl** and (**P**), the ratio between Gray and inverse Roentgen being as follows: 1Gray(Gr) = 113 P = 0,029 Kl/kg.

As it has been already mentioned, the radiographic film class is the combination of required sensitometric parameters of films that provide obtaining a radiographic image of corresponding quality. Three classes of radiographic images have been introduced to distinguish between requirements to objects testing in different fields of application, that is, objects under the supervision of Gosatomnadzor (State Committee of Nuclear Power Control) and Gostechnadzor (State Committee of Technical Control) of Russia; metallic constructions, hydraulic stations and other objects that are independent on any supervision authorities. The suggested Russian draft Standard has three significant distinctions from currently existing standards:

1. Sensitometric parameters are determined not only under the voltage of 80kV applied to the X-ray tube, as it is recommended in [14], but also under the voltage of 220kV.

2. Apart from the definition of contrast gradient, the definition of gradient is introduced, the latter having been determined only for medical purpose films.

3. Sensitometric parameters are determined, as it was done earlier, under the density 0,85 + D_0 if the voltage on the X-ray tube is 80 kV, and under the density 2,0 + D_0 if the voltage is 220 kV.

The above mentioned differences make the Russian radiographic materials classification closer to European and International Standards. However, the drastic difference of the Russian draft Standard from the International and European ones is that it does not include the main criterion which has a decisive effect on the image quality, that is the ratio **signal/noise**. Moreover, the standard method of photographical development is missing in the draft. The other difference, not very important though, between the draft and the European and International Standards is the use of impulse radiation source, alongside with the permanent radiation source for films classifying.

Methods of research. According to the classification accepted in Russia, the criterion for dividing radiographic films into classes is sensitivity. To measure sensitivity and other sensitometric parameters, radiographic materials have been exposured to radiation on the X-ray sensitometric apparatus of the Renex type without using intensifying screens. The X-ray tube RID-1 (РИД-1 in Russian) of the 20-50 BD22-150 (20-50БД22-150) type, with rotating anode was used. The voltage on the tube was 80kV, exposure time being 50 and 100 sec. The speed of the cassette rotation was 90 revolutions per minute. After the exposure the step wedge was processed in the standard developer “Rentgen-2” under the temperature 20^0C ± $0{,}5^0$ for 6 minutes. The rest of operations were carried out in accordance with the procedure description in [14]. Classes of radiographic films were determined taking into consideration the combination of parameters suggested by the Russian draft Standard [1,2,3]. They can be seen in Tab.1.

Table 1. Classes of radiographic industrial films

Class	The film type	Manufacturing company	Country	Sensitivity, p^{-1}, of the film $S_{0,85 + D0}$
1	PT-14	TASMA	Russia	**2,6**
	PT-15	TASMA *	Russia	**1,4**
	DR50	KODAK	France	**1,4**
	M100	KODAK	France	**2,6**
	D2	*AGFA - Gevaert	Belgium	**1,4**
	D3	AGFA - Gevaert	Belgium	**2,6**
	NDT35; NDT45	DU PONT	Germany	**1,5; 2,7**
	IX 25; IX 50	FUJI	Japan	**1,5; 2,7**
2.	PT-4T	TASMA	Russia	**4,0**
	PT-5Д; PT- K	TASMA	Russia	**5,0; 7,0**
	MX 125	KODAK	France	**4,5**
	T 200	KODAK	France	**6,5**
	D4	AGFA - Gevaert	Belgium	**4,5**
	D5	AGFA - Gevaert	Belgium	**6,5**
	P4, R4	FOMA	Czechia	**4,5**
	P5 *,R5	* FOMA	Czechia	**5,5**
	NDT45; NDT55	DU PONT	Germany	**2,7; 6,5**
	IX 80	FUJI	Japan	**4,5**
3.	PT-7T	TASMA	Russia	**8,0**
	PT-12; PT-8T	TASMA	Russia	**12**
	P7, R7	FOMA	Czechia	**11,0**
	P8,R8	FOMA	Czechia	**17**
	D7	AGFA - Gevaert	Belgium	**11**
	D8	AGFA - Gevaert	Belgium	**15**
	AX	KODAK	France	**9,0**
	AA 400,	KODAK	France	**11**
	CX 800	KODAK	France	**16**
	HS 800	KODAK	France	**19**
	NDT65, NDT70	DU PONT	Germany	**12; 16**
	IX 100	FUJI	Japan	**11**
	IX 150	FUJI	Japan	**17**
	KX 221	CNC LUCKY	China	**19**
4.	PT-1B	TASMA	Russia	**35**
	PT-1, PT-11	TASMA	Russia	**30, 40**
	*P1, RX 1	FOMA	Czechia	**27**

Footnotes:

- The “KODAK” company produces film radiographic systems under the trademark“Kodak Industrex”.
- The “AGFA-Gevaert” company produces film radiographic systems under the trademark “Structurix”.
- The “FOMA” company produces film radiographic systems under the trademark “Fomadux”.

- **P -** means: made of semi-product produced in the Czech Republic.
- **R** –means: delivered from the Czech Republic, “FOMA”.
- The “DU PONT” company produces film radiographic systems under the trademark “DU PONT”.
- The “LUCKY” company produces film radiographic systems under the trademark “ INDUSTRIAL X-RAY FILM”.

All kinds of X-ray sensitometric characteristics, layers thickness and surface silver concentration in emulsion layers of radiographic X-ray films can be found in Table 2.

Table 2. Sensitometric characteristics, layers thickness and surface Ag concentration in layers

Film type	**Exposure time (in sec)**	**X-ray sensitometric parameters**							**Layers thick-ness (mcm), surface Ag conc. in layer, g/m^2**
		$S_{0,85+Д0}$ $Р^{-1}$	**γ**	**G**	**D_0, Б**	**R, $мм^{-1}$**	**σx1000 D=2,0**	**G/σ**	
TASMA									
PT-15	100	1,4	4,9	4,5	0,05	195	16	281	22, 17,0
PT-14	100	2,6	5,1	4,4	0,06	180	18	232	23, 17,0
PT-5Д	100	5,0	4,6	4,0	0,03	180	25	160	17, 11,5
PT-K	100	7,0	4,7	4,2	0,04	180	24	191	18, 11,5
PT-4T	100	4,0	4,2	3,8	0,02	195	18	211	18, 11,5
PT-7T	100	8,0	4,9	4,4	0,04	180	26	161	19, 13,0
PT-8T	100	14	4,6	4,0	0,04	145	30	133	19, 13,0
PT-12	100	12	4,5	3,8	0,06	160	30	125	22, 16,0
PT-11	50	40	4,2	3,9	0,10	65	61	64	27, 23,0
PT-1	50	30	4,2	3,9	0,08	65	62	63	23, 13,5
PT-1B	50	35	4,0	3,7	0,08	65	61	61	23,13,5
FOMA									
R4	100	5,0	4,4	3,8	0,04	175	24	158	18, 13,3
R5	100	7,0	5,0	4,0	0,06	160	25	160	25, 14,1
R7	100	11	5,0	4,0	0,05	145	32	125	32, 18,1
R8	50	17	4,5	3,9	0,04	135	39	100	31, 20,2
R1	50	27	4,0	3,2	0,08	65	64	50	22, 13,6
AGFA-Gevaert									
D2	100	1,4	6,4	5,1	0,04	195	13	392	
D3	100	2,6	5,2	4,8	0,05	180	16	303	

D4	100	4,5	5,3	4,6	0,05	180	20	232	20, 12,2
D5	100	7,0	5,2	4,6	0,06	160	26	177	21, 14,5
D7	100	11	5,1	4,6	0,06	145	32	144	25, 15,4
D8	50	15	4,7	4,1	0,08	120	35	117	
KODAK									
DR	100	1,4	6,5	4,9	0,02	215	13	378	
M	100	2,6	5,2	4,8	0,02	195	15	320	26, 17,6
MX125	100	4,5	5,3	4,3	0,03	180	19	226	19, 12,6
T200	100	6,5	4,8	4,1	0,04	180	24	170	
AX	100	9,0	5,1	4,2	0,06	160	30	140	22, 14,2
AA 400	100	12	5,3	4,2	0,05	160	30	140	22, 13,0
CX 800	50	16	4,1	3,7	0,08	145	30	124	15, 9,2
HS 800	50	19	4,6	3,9	0,07	145	30	130	16, 9,5
FUJI									
IX 25	100	1,5	5,3	4,6	0,04	195	14	328	25, 13,4
IX 50	100	2,7	4,7	4,0	0,04	180	17	235	25, 14,1
I X 80	100	4,5	4,8	4,2	0,04	160	21	200	25, 13,5
I X 100	100	11	5,2	4,4	0,04	145	32	137	25, 14,4
I X 150	50	17	4,8	4,1	0,04	135	35	117	25, 15,3
LUCKY									
KX221	50	19	3,8	3,1	0,05	145	34	90	22, 18,9

Footnotes:

$S_{0,85+Д0}$ - radiation sensitivity under the criterion density 0,85 + $Д_0$,

γ - reflectance ratio,

G - gradient,

D_0 - optical density of fog,

R - resolving capasity,

$σ_д$·1000 - mean-square graininess,

G/ σ - ratio signal/noise

Conclusions

1. An attempt has been made for the first time to systematize X-ray sensitometric and structuremetric characteristics, surface concentration of metal silver and emulsion layers thickness of various radiographic industrial films produced both in Russia and abroad.

2. The analysis of distinctions between International and European standards and the Russian draft Standard suggested for classification of radiographic films has been carried out.

3. The possibility of using Russian radiographic industrial films instead of similar films produced overseas and having higher prices has been demonstrated.

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