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MODERNIZATION OF OPTICAL MICROSCOPE AND ITS USE TO OBTAIN DIGITAL IMAGES OF MICROSTRUCTURE OF DEPOSITED METAL

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The article analyzes the methods of modernization of optical microscopes to obtain digital images and simplification of their subsequent analysis during basic metallographic examinations of deposited metal specimens. Two main methods of modernization were considered: with the help of a camera, equipped with special adapters, which is attached to the tube of the microscope eyepiece and with the help of a video eyepiece, which is mounted instead of a standard microscope eyepiece. The main advantages and disadvantages of each method were noted. With the help of the metallographic microscope MIM-7, camera Canon 650D, video eyepiece SIGETA MCMOS 3100, as well as specimens of microsections with a deposited layer of semi-heat-resistant steel of C–Cr–Mo–W–V alloying system, comparative metallographic examinations were performed. It is shown that the use of the special video eyepiece SIGETA MCMOS 3100 allows obtaining digital images of metal microstructures with a higher quality. As an illustration of the main advantages of the work, provided by the use of the equipment modernized in such a way, the results of metallographic examination of the metal, deposited by electric arc method using flux-cored wire PP-Np-120V3KhMF, were provided. It was experimentally established that the software Toupview, supplied with the eyepiece SIGETA MCMOS 3100, used during these examinations, allows easy processing of the obtained digital images, which greatly expands the capabilities of basic metallographic analysis. 10 Ref., 7 Figures.

Keywords: metallography, optical microscope, video eyepiece, arc surfacing, flux-cored wire, deposited metal, semi-heat-resistant steel

For today, in many modern metallographic research laboratories special digital microscopes are used, where the image, obtained from the optical system of the device, is transmitted directly to a high-definition light sensor, which allows carrying out its further computer processing easily [1]. Most often, the observations of a studied object is carried out either through the built-in LCD screen, or through the screen of laptop or personal computer, to which the microscope is connected. This significantly simplifies a preliminary search and examination unlike when it is necessary to look all the time into the microscope eyepiece.

In addition, having a digital image of the studied objects, using the appropriate software (further SW), it is possible to apply special filters, highlight the required areas, «glue» several images into one, carry out different measurements, etc., which greatly expands the capabilities of the basic metallographic analysis, reduces the time and complexity of its implementation [2]. Taking into account the fact, that during the development of new materials or surfacing technologies it becomes necessary to perform a large amount of preliminary experiments on the manufacture and study of macro- and micro-sections of the deposited metal, the task of simplifying the basic metallographic analysis is quite relevant.

However, at present some of the research laboratories are still equipped with the optical microscopes MIM, METAM, MMU and other models, where the optical system allows obtaining a sharp image with a magnification of up to 1000 times, but they have no possibility to obtain digital images of the studied objects.

The aim of the work is analyzing and choosing the ways to modernize optical microscopes to obtain digital images and to simplify their subsequent analysis during basic metallographic examinations, as well as to illustrate the capabilities of the modernized metallographic equipment on the example of studying the structure of semi-heat-resistant deposited metal of the alloying system C–Cr–Mo–W–V.

Analysis of ways of modernizing optical microscopes. Taking into account the high cost of both modern digital microscopes, as well as comprehensive professional modernization of existing optical microscopes, many researchers are trying to carry out modernization «on their own». For this purpose, either different digital cameras or special video eyepieces are often used.

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In the first case, the problem is solved in several ways. Thus, photographing can be performed directly through the eyepiece of the microscope, but this method has significant disadvantages [3, 4]:

• need to provide a rigid attachment of the eyepiece to the camera and alignment of their optical systems;

• need to provide protection against side light-striking;

• additional optics (camera lens) often deteriorates the image quality, reducing its sharpness and brightness.

To eliminate these drawbacks, photographing through the microscope eyepiece can be performed by the camera without its lens, instead of which the optics of the microscope is directly used [3, 4]. In this case, two schemes of work are possible: photographing through the lens and eyepiece of the microscope or only through the lens of the microscope (Figure 1). In both cases, the image is focused only by the microscrew of the microscope by the image on the camera screen.

However, as the experience of using the above-described schemes shows, images with the highest quality can be obtained at low magnifications (not more than ×100), or with the use of additional special expensive optics. For example, in [5] the operability of a similar modified model of the microscope Lomo Metam R-1 by replacing the eyepiece with a digital SLR camera Canon 650D. Therefore, the image was projected to the matrix without the use of the eyepiece of the microscope and the lens of the camera, as is shown in the scheme in Figure 1, *b*.

Using a modified microscope, the authors of [5] obtained digital images at magnifications ×10–×40 (Figure 2). The Figure shows that at a magnification of ×40, the image quality becomes worse — the standard illumination is clearly insufficient to obtain a quality image. Thus, the use of the scheme shown in Figure 1, *b* significantly limits the capabilities of the researcher because of the fact that a total magnification of the microscope in this case will be provided only by its own magnification of the used microscope lenses (usually within ×4–×90) and the abilities of a digitally camera scaling. In addition, the image itself at all magnifications is «clogged» with black edging of the microscope tube.

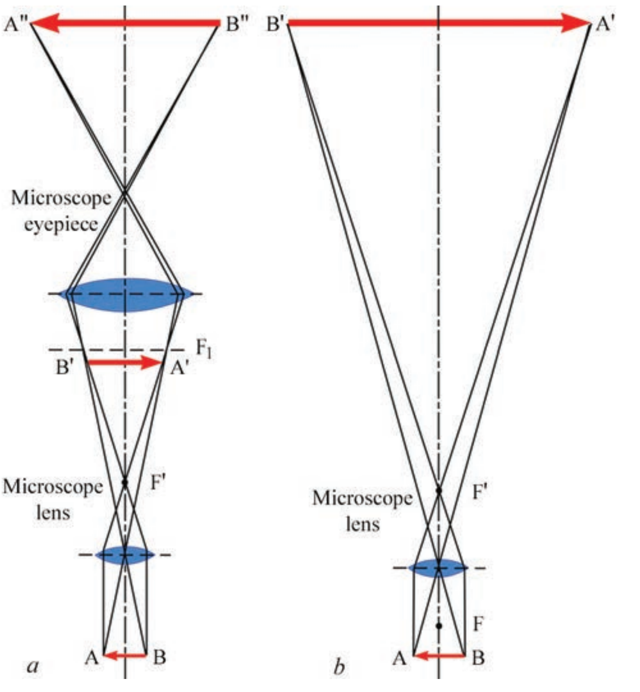

Figure 1. Movement of rays during photographing with the microscope lens and eyepiece (*a*) and with the microscope lens only (*b*) [4]

As is seen, obtaining digital images from the optical microscope using conventional digital cameras is associated with certain difficulties in providing a good quality of images and the need to purchase a camera with the ability of replacing the lens, special adapters for a particular brand of camera and microscope and also such additional equipment, as external illuminators, etc.

The abovementioned disadvantages include the need of making special adapters for mounting the camera on the microscope and the lack of native SW for processing the obtained digital images. Such SW allows performing calibration of the system necessary for carrying out geometrical measurements and the

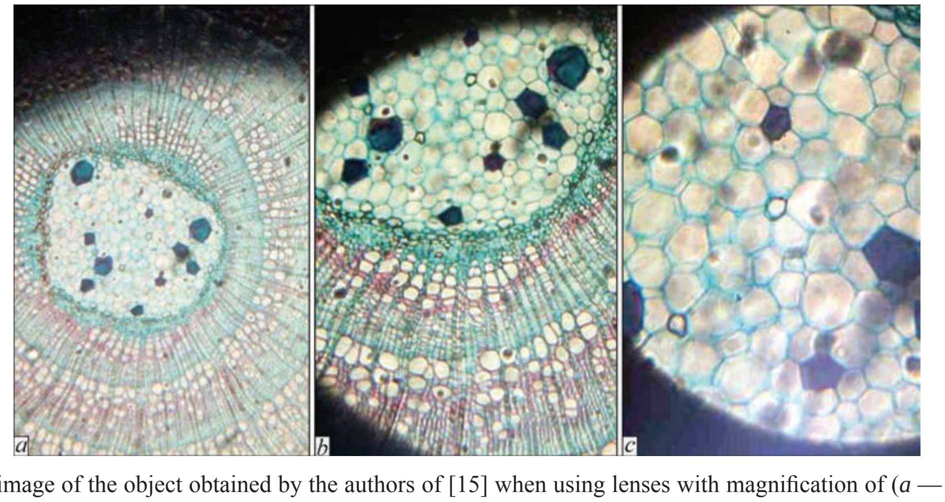

Figure 2. Digital image of the object obtained by the authors of [15] when using lenses with magnification of (*a* — ×10); (*b* — ×20) and (*c* — ×40)

subsequent quantitative analysis and in case of acquisition of special video eyepieces, it is delivered, as a rule, in a set with them.

Therefore, there can be only three advantages of using digital camera together with the optical microscope, they include a high light sensitivity, high separating capability of images and ability of long-term exposures. However, these advantages also depend on the cost of the used equipment as far as manual adjustments of these parameters are possible in the professional cameras.

Based on the abovementioned, it looks more attractive to use special video eyepieces, which allow working with the image in real time directly on the computer monitor. The advantage of such equipment is the simplicity of its installation instead of the native eyepiece, as well as the compliance of the separating capacity of the digital eyepiece to the used magnification, which allows obtaining images with a maximum detailing without extraneous «noises», which significantly increases the accuracy and reproducibility of measurement results [6, 7].

Thus, in [6] the investigations were performed in the microscope MIM-8, instead of whose eyepiece, a digital camera Scope Tek DEM35 was installed, which allowed obtaining high-quality images of microsections of cast irons of grades SCh15 and VCh400-12 and carry out the further analysis of these images. In [7] to study the microstructure, the metallographic microscope Metam LV-42 at a magnification of ×50×1000 together with a digital eyepiece CAM V200 was used.

The cost of digital video eyepieces is determined first of all by the separating capacity of the resulting image, as well as the presence of a special optical unit (homal) at a certain magnification (most often ×10). The presence of the homal is necessary not only to obtain images at a higher magnification, but also to improve the quality of the image itself, as far as the homal serves as a compensation eyepiece to correct image defects due to a chromatic aberration and especially to rectify the curvature of the image plane. The cost of such video eyepieces is also affected by the

Figure 3. Photography equipment used for modernization of the microscope MIM-7: camera Canon 650D with adapters made for it (*a*); video eyepiece SIGETA MCMOS 3100 with set adapters and SW Topview (*b*)

convenience, efficiency and a number of measuring tools in the SW that is supplied with the eyepiece [2].

The use of such SW during the subsequent processing and analysis of digital images allows providing a partial automation of this process, significantly reducing the time and labor intensity, in particular, while conducting metallographic analysis, as well as increasing in the accuracy of the results [2]. The examples of such SW paid Thixomet and ZEISS Axiovision, as well as free, such as imagej, Jmicrovision and other may be [6–9].

Comparative analysis of two methods of microscope modernization. Based on the abovementioned, in order to determine the best way to modernize the optical microscope, it was decided to conduct comparative studies of the quality of the obtained digital images using the following equipment: optical metallographic microscope MIM-7, digital camera Canon 650D and video eyepiece SIGETA MCMOS 3100. Due to the fact that the video eyepiece SIGETA is supplied with the homal at the own magnification of ×10, to provide the same conditions, photographing with the camera was performed without its lens with a standard eyepiece, mounted in the microscope tube at the same magnification of ×10 (i.e. according to the scheme, shown in Figure 1, *a*). The lens of the microscope in both cases was the same — achromatic epic lens LOOMP F-6.2; A-0.65, at the own magnification of ×32.

As far as the microscope MIM-7 is not equipped with a standard system for connecting camera to it, special adapters were made, which were put on the tube of the microscope eyepiece and allowed attaching camera to it (Figure 3, *a*). At the same time, mounting of the video eyepiece SIGETA (Figure 3, *b*) on the microscope was much simpler, because it already includes several adapters for the most common diameters of the microscope eyepiece tube. The appearance of the microscope MIM-7, additionally equipped with a camera and video eyepieces, is shown in Figure 4.

To provide an example, a comparison of the quality of digital images obtained from the digital camera Canon 650D and the video eyepiece SIGETA MCMOS 3100 was performed applying microsections of the metal deposited using the flux-cored wire of the alloying system C–Cr–Mo–W–V (PP-Np-120V3KhMF) [10].

The specimens for microstructure examinations were cut out from St3 steel billets deposited in four layers using this wire. The structure of the deposited and base metal was detected by chemical etching in a 4 % alcoholic solution of the nitric acid HNO_3. Before the measurements, the microscope and SW were calibrated using a micrometer object.

Results of comparative analysis of two methods of microscope modernization. Significant differences

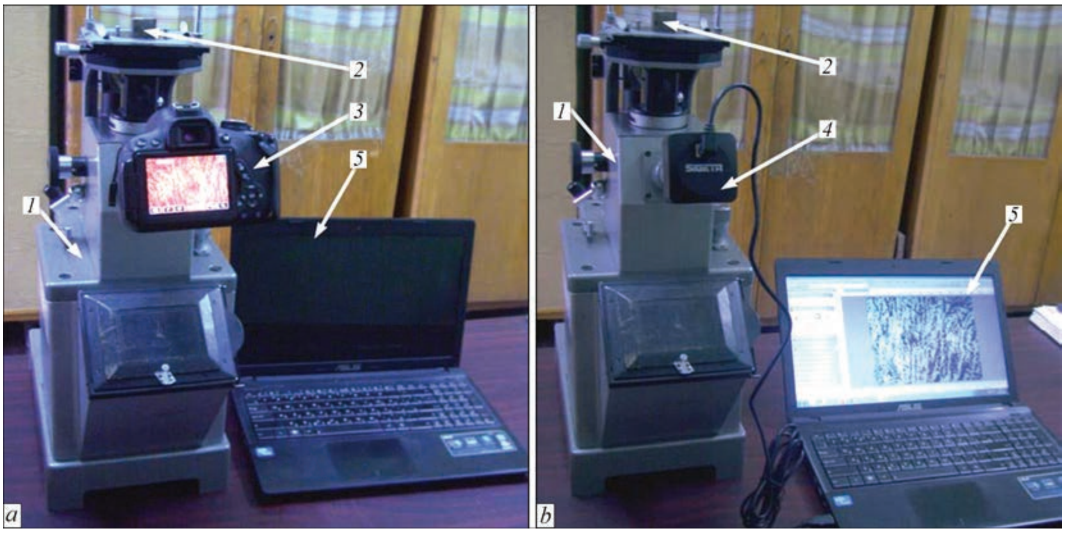

Figure 4. Modernized microscope MIM-7 when using camera (*a*) or video eyepiece (*b*): *1* — microscope MIM-7; *2* — test specimen; *3* — camera Canon 650D; *4* — eyepiece SIGETA; *5* — laptop with a special SW

in the use of the camera and video eyepieces to obtain digital images in the optical microscope are observed at the early stages of work during setting up the equipment. In case of using camera, it is necessary to correctly adjust the exposure value, aperture, light sensitivity, white balance, etc., because automatic adjustments often do not allow obtaining an acceptable image quality. It is rather problematic to do this operation at a high level, looking at a small screen of the camera (Figure 4, *a*). In addition, using the camera settings it was still failed to remove the yellowness of the image provided by the incandescent lamp used in the microscope MIM-7.

After mounting the video eyepiece SIGETA in the microscope tube, it is connected to the computer using USB cable and with the help of the SW supplied in the set with the video eyepiece, it displays the resulting image on the screen (Figures 4, *b*). It is much easier to sharpen and search for the desired area of the microsection on the big screen, and due to the wide capabilities of SW Toupview, manual adjustment (if automatic settings do not suit the user) of the image quality obtained from the microscope takes no more than a few minutes. With the help of «sliders», the user can change such parameters as exposure, white balance, color tone, saturation, brightness, contrast, sharpness, etc. in real time, reaching the maximum quality of the resulting image. Also, using the built-in capabilities of SW, it is possible to reduce the «noise» of the image, highlight objects of the same color, «stitch» several images into one, etc.

For comparison, the images of the same areas of the specimen obtained using the digital camera Canon 650D and the video eyepiece SIGETA at the same magnification (×320) are shown in Figure 5. As is seen, the use of the video eyepiece SIGETA allows obtaining a higher quality and detailing of the image as compared to using digital camera. In addition, the sharpness of the images obtained with the help of the camera is not the same over the entire area of the image — the area of sharpness in the central part of the

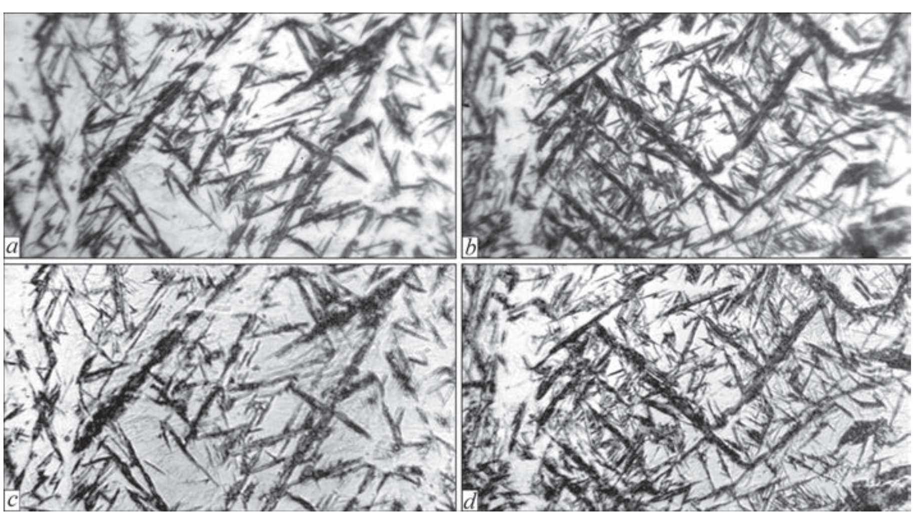

Figure 5. Microstructure (×320) of the specimen deposited using the wire PP-Np-120V3KhMF. Photo taken with the camera Canon 650D (*a*, *b*) and video eyepiece SIGETA MCMOS 3100 (*c*, *d*)

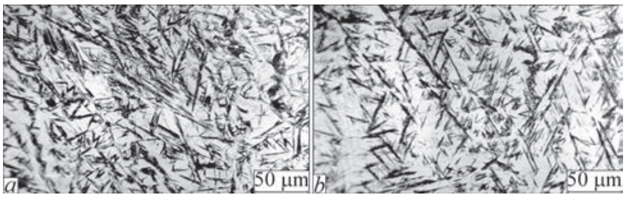

Figure 6. Microstructure (×320) of metal in the center (*a*) and at the upper edge (*b*) of the layer deposited using the flux-cored wire PP-NP-120V3KhMF

image occupies about 45 % of its total area (Figure 5, *a*, *c*). The image obtained with the help of the video eyepiece SIGETA has a more uniform sharpness over almost the entire area of the image (Figure 5, *b*, *d*). In this case, the area with a good sharpness amounts to more than 85 % of the image area.

Taking into account the advantages of using the video eyepiece SIGETA described above, as an illustration, the abilities of operation with this equipment and SW Toupview during metallographic analysis are given more fully below.

The structure of the metal, deposited using the flux-cored wire PP-Np-120V3KhMF consists of martensite with large and small needles of different etching and a small amount of residual austenite (Figure 6, *a*). At the upper edge of the deposited metal, the amount of residual austenite increases slightly, and the size of martensite needles, on the contrary, decreases (Figure 6, *b*). In this case, the typical structure of the cast metal is preserved along the entire height of the deposited layer. Analysis of the structure of the metal in the heat-affected-zone (HAZ) showed (Figure 7, *a*), that it consists of a ferrite-pearlite mixture, here the amount of ferrite predominates.

It should be noted that in the deposited specimens, individual pores were revealed in the lower layer of the deposited metal, near the fusion line (Figure 7, *b*). The average pore size is 76 μm. Also, on the polished non-etched specimens, the sizes, amount and number size of nonmetallic inclusions were determined. In the studied specimens oxides, sulfides and oxisulfides were revealed. The amount of inclusions is small, they are located rather uniformly and have a predominantly round shape. The volume fraction of inclusions in the metal deposited by the test flux-cored wire PP-Np-120V3KhMF was 0.18 %.

Conclusions

1. There are several different methods for modernization of optical microscopes with the purpose of obtaining digital images, the most appropriate of which is the use of digital video eyepieces, which are mounted directly into the microscope tube without any additional manipulations. It is possible to significantly accelerate and simplify measurements when performing basic metallographic analysis using a specialized SW for digital image processing.

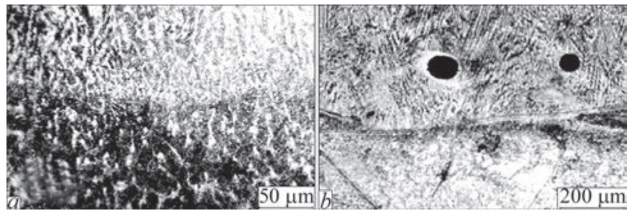

Figure 7. Microstructure of metal near the fusion line in the specimen deposited using the wire PP-Np-120V3KhMF: *a* — ×320; *b* — ×90

2. With the help of microsections of the metal deposited using the flux-cored wire of the alloying system C–Cr–Mo–W–V (PP-Np-120V3KhMF), the main advantages and capabilities of the metallographic analysis, carried out by means of the microscope MIM-7, modernized by mounting the video eyepiece SIGETA MCMOS 3100 and using SW Toupview 3.7 are shown.

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