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ResearchArticle

Comparison of Experimental Curves of Alloy Steels after Gas Nitriding

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Abstract:

This study is concerned with experimental curves of: hardness, residual stress and concentration of nitrogen at the precipitation layer at alloy steels after gas nitriding. The purpose of this treatment is that through experimental curves to identify the relationship and causality between hardness, on one side, and on the other, residual stress respectively concentration of nitrogen. Comparing the shape and slope of these curves we can conclude that, concentration of diffused nitrogen on the steel lattice, respectively ferrite, is a cause of increased hardness at the precipitation layer. More to the point, as a result of nitrogen diffusion, residual stress emerge which cause increase of hardness. The intensity and slope of the curves of hardness depends on the intensity and slope of the nitrogen concentration respectively residual stress.

1. Introduction

With the aim of improving the physical characteristics of iron materials, and more specifically of steels, various methods are used, and one of them is nitriding [1-8]. This process takes place in temperatures of over 500^{0}C and in solid, liquid or gas environments [9]. Irrespective of the environment in which nitriding takes place, the aim is almost the same: enriching the steel's surface with atomic nitrogen. As a result of the diffusion (enrichment) of the nitride on the surface of the material, physical changes occur within it and these are noticeably improved by the conditions of application of different equipment [10-14]. In this paper we deal with the results of nitriding of two types of steel in gas environments. Specifically, we have researched the effect of nitriding on 16MnCr5 and 31CrMoV9 steel in the temperatures of 550^{0}C and 590^{0}C and over two periods of time, giving a total of eight samples.

2. Method

The nitriding process was carried out in an air dopped ammonia atmosphere with the nitriding potentials as given in Table 1, while the nitriding period was chosen such that comparable layers of nitriding could be obtained for different temperatures as in Table 2.
Before the samples were investigated experimentally they were prepared metallographically with grinding and polishing of their surface. The details of specimen preparation are given in our earlier papers [11, 15]. The chemical analysis of the samples was carried out with a spark emission spectroscopy (Jobin Yvon, model JY-132F), and the results are listed in Table 3. The experimental research methods were: Vickers method for hardness measurements, Electron Probe Micro-Analysis (EPMA) for

nitrogen-depth profiling, and X-ray diffraction (XRD) method for residual stress analysis.

Hardness measurement were performed on polished cross-sections of nitrided specimens by using a PCE Leco hardness tester under a load of 0.9807 N ($HV_{0.1}$). The distance between two succsesive measuring points was 50 µm. For comparison purposes, five more hardness measurements were taken outside of the nitrided area, i.e., in the matrix. Nitrogen concentration-depth profiles were determined with a Joel JXA-8900RL microanalyser operated at 20 kV and 40 nA. EPMA measurements were performed on polished cross-section of nitrided specimens, perpendicular to the surface, starting at the surface and moving in 5 µm increments towards the depth. Residual stresses were evaluated with XRD by using a Huber diffractometer with Cr-Kα radiation on the {211} diffraction plane of α-Fe. The $\sin^2\psi$ method [16-18] was used with the following measuring conditions: voltage/current X-ray tube parameters 40 kV/30 mA, measuring interval $\sin^2\Psi = 0$ to ± 0.5, measuring step width $\Delta\sin^2\Psi = 0.1$, measuring time interval 10-20 s, α-Fe elastic constants $E_{(211)} = 220$ GPa and $\nu_{(211)} = 0.8$.

Table 1. *Nitriding parameters*

Temp./ °C	**The atmosphere of nitriding**	**Nitriding potential, K_n**
550	Air dopped ammonia gas	3
590	Air dopped ammonia gas	2.82

Table 2. *Sample labelling, nitriding temperature and time*

Temp./ °C	**Time /h**	**Sample label**	
		16MnCr5	**31CrMoV9**
550	9	16-9	31-9
	64	16-15	31-15
590	4	16-17	31-17
	36	16-23	31-23

3. Results and Discussions

For each sample we found experimental curves for strength (HV), residual stress (RS), and the profile of distribution of nitrogen (N). Subsequently, with the aim of comparing the experimental results, we presented the curves jointly in a graphic. In order to for the comparison to be clearer, we normed the maximal values of HV, RS and N as 1 so that on the y axis we can see the relative impact of these values on depth. The results were displayed in figüre 1-8.

4. Conclusions

The intensity of curve N is in proportion with that of RS and HV. The more nitride diffuses in the steel network (the greater the intensity of curve N) the higher the intensity of residual stress RS. This is the case because during nitriding, deformation occurs to the steel network which produces stress in (negative) pressure. Likewise, the intensity of the residual stress RS is comparable with that of HV. In this assessment we consider that the diffusion of nitrogen causes residual stress in the network and as a result an increase occurs in the HV strength of the steel. Since the diffusion of nitrogen depends on the nitriding conditions it is possible to change the physical characteristics of steel and in this specific case by using the parameters of nitriding – time, temperature, nitriding potential and the type of steel.

Table 3. *Chemical composition (in wt.%) of steels. The difference to 100 wt.% is Fe*

	16MnCr5	**31CrMoV9**
C	0.18	0.29
Cr	0.71	2.17
Mn	1.06	0.70
V	0.001	0.15
Mo	0.009	0.27
Si	0.31	0.26
S	0.026	0.004
P	0.028	0.016
Al	0.088	0.022

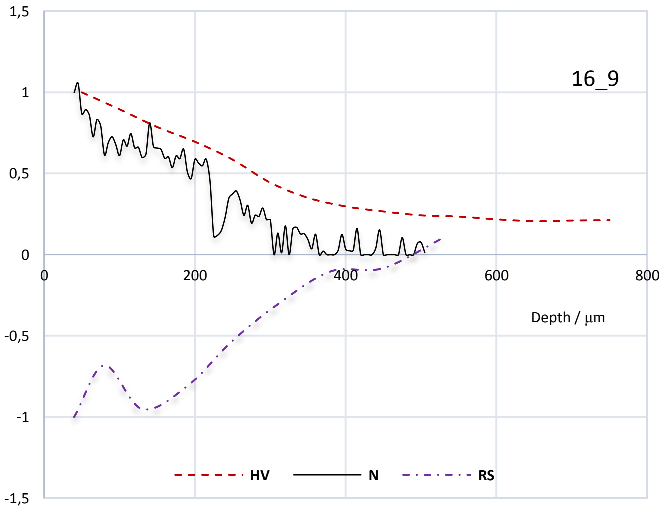

Figure 1. *HV, RS and N curves for sample of 16_9 (see table 2)*

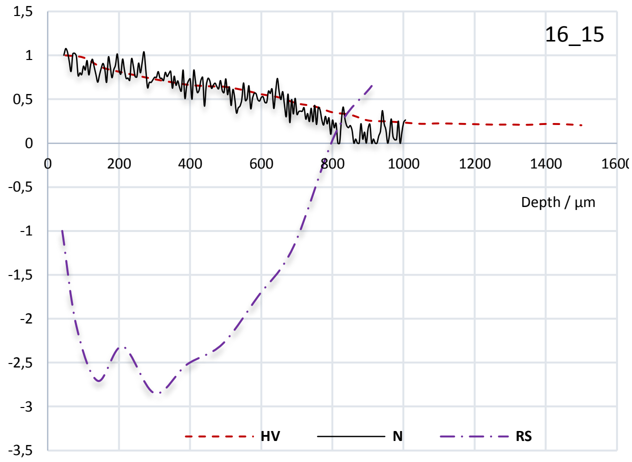

Figure 2. *HV, RS and N curves for sample of 16_15 (see table 2)*

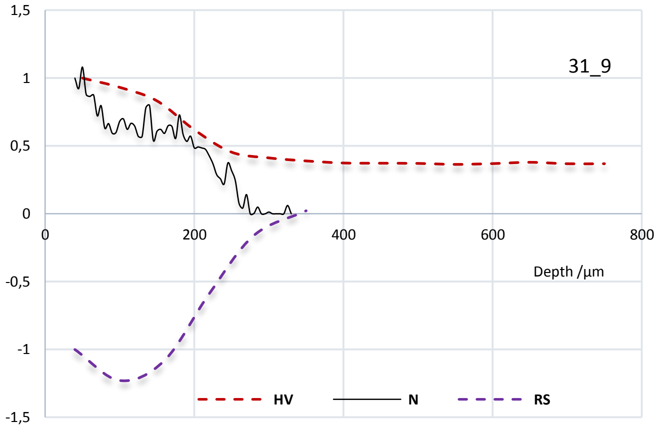

Figure 5. *HV, RS and N curves for sample of 31_9 (see table 2)*

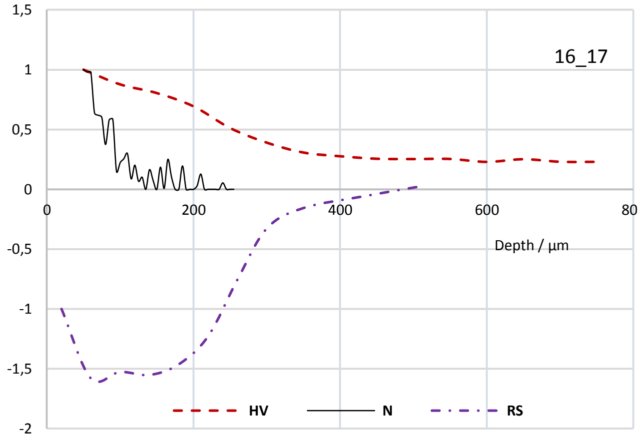

Figure 3. *HV, RS and N curves for sample of 16_17 (see table 2)*

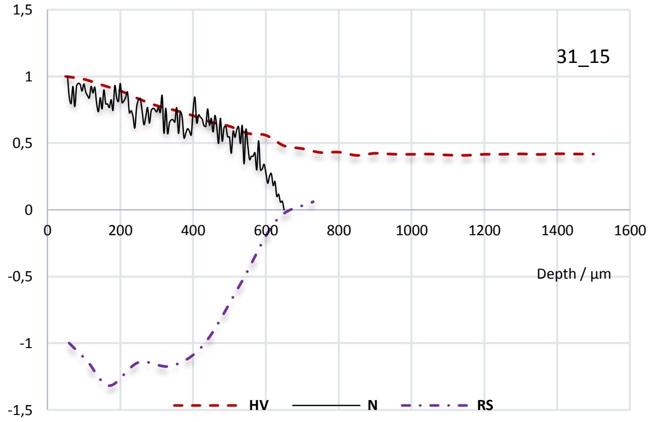

Figure 6. *HV, RS and N curves for sample of 31_15 (see table 2)*

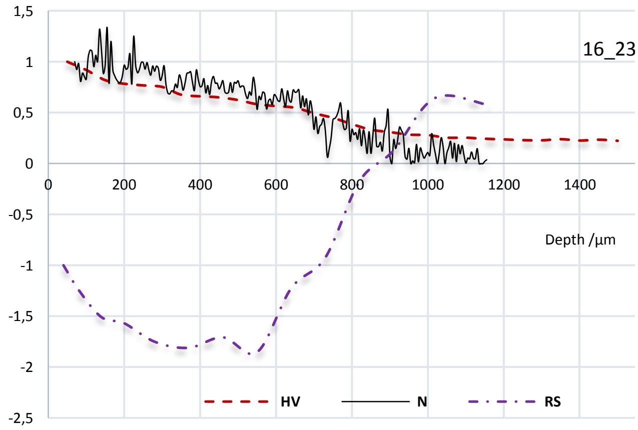

Figure 4. *HV, RS and N curves for sample of 16_23 (see table 2)*

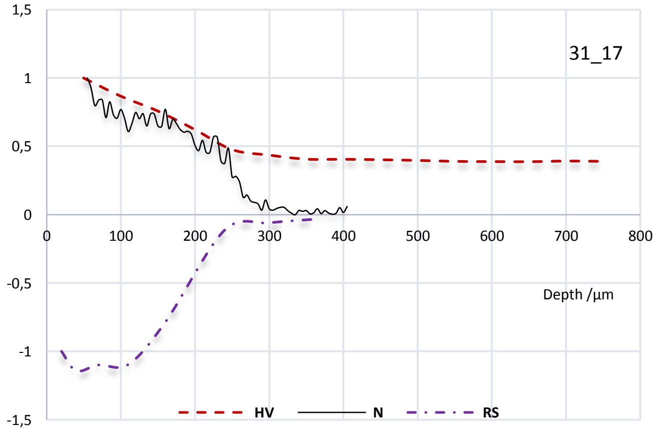

Figure 7. *HV, RS and N curves for sample of 31_17 (see table 2)*

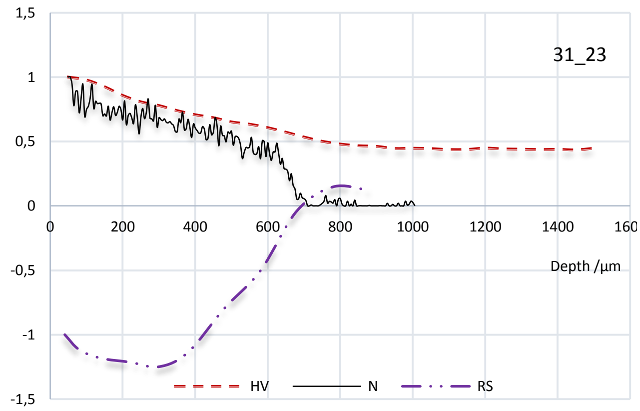

Figure 8. *HV, RS and N curves for sample of 31_23 (see table 2)*

Author Statements:

- The authors declare that they have equal right on this paper.
- The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- The authors acknowledge that this paper presented as oral presentation in ICCESEN

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