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LASER TREATMENT OF T1-HIGH SPEED TOOL STEEL

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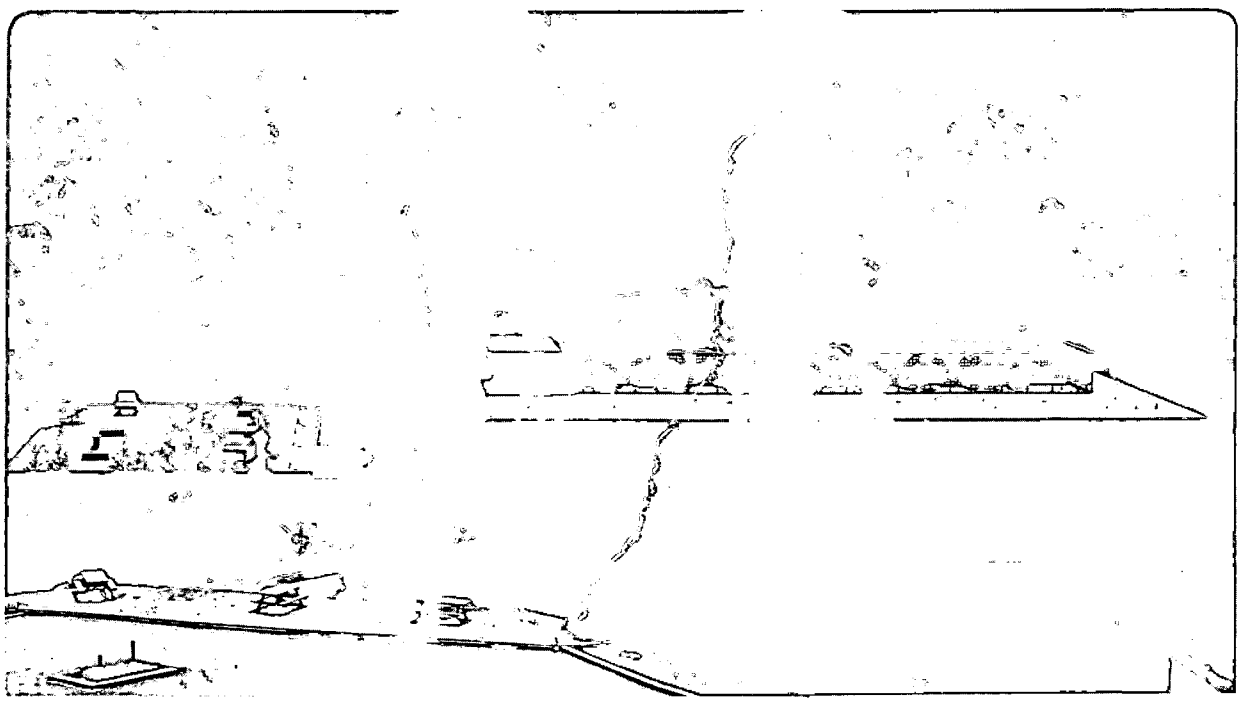

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LASER TREATMENT OF T1-HIGH SPEED TOOL STEEL

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Metallographic (optical, TEM, SEM), spectroscopy and microhardness investigations of high tool speed steel - T1 (0.85% C, 18.5% W, 4.2% Cr, 1.2% V) heated by pulsed neodymium and continuous CO_2 lasers are described. The martensite, retained austenite and M_6C carbides were observed in the laser-melted zones. The higher chemical homogeneity and finer structure of pulsed neodymium laser-melted zones compared to CO_2 laser melted zones was interpreted as a result of the higher speed of cooling. Fine cellular precipitates of M_6C carbides during tempering were formed. An increasing of microhardness in the laser melted zones with temperature of tempering was observed and explained as a result of this precipitation prosesses.

I. Introduction

Laser beams provide a controlled source of heat by which materials can be machined or surface treated with exceptionally high rates of heating and

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cooling. Recent applications of lasers to materials processing include surface melting, alloying, cladding, heat treating and shock hardening.[1-4] Steels, which have been heated with high rates by laser radiation, electron beam or by other sources of energy and then cooled very quickly, show certain singularities in comparison to steels which are conventionally heat treated. The reasons for this, are not only the extreme rates of heating and cooling of the material but frequently also the high pressure which involves both elastic and plastic deformation of the lattice. Lasers have a notable influence on the changes of equilibrium conditions, phase transformations and also on the dissolution and precipitation processes. The laser beam when used as a heat source for heat treatment can affect the metal surface in two ways:

1) It can cause transformation hardening without melting or significant roughening of the surface, i.e., laser transformation hardening, or
2) It can melt a thin, uniform film on the surface, i.e., laser glazing or melting.

Laser transformation hardening and laser glazing are nearly similar processes although, unlike transformation hardening which induces solid state phase transformations, the laser glazing process rapidly melts and resolidifies metal surfaces. Structural refinement caused by the rapid solidification hardens many alloys, an effect which could well improve their resistance to wear.[2] The structure which is formed after laser glazing has many interesting properties, for instance: high homogeneity, resistance to wear, high hardness and highly refined microstructure. From a practical standpoint laser glazing will undoubtedly produce interesting microstructures in many materials; a particularly interesting class is that of high speed tool steel. In these alloys one anticipates that a significant improvement in machining properties

and tool lifetime will result from an extremely small grain size and a homogeneous dispersion of fine carbide particles. These desirable microstructural characteristics have also been recognized by various workers like: Rayment and Cantor,[3] Strutt and Nowotny,[4] and Kear, Breinan, Greenwald,[5] who studied the effect of splat quenching tool steels. It was also shown in our earlier research that the life for cutting is about two to three times higher for the laser treated knives compared to knives after traditional heat treatment.[6]

II. Material and Experiments

This article presents the results of an investigation of the changes in the phase and chemical composition, microstructure and hardness of a laser melted high speed tool steel, namely T1 (0.85% C, 18.5% W, 4.2% Cr, 1.2% V). Before laser treatment the samples were heat treated conventionally by hardening and tempering. Pulsed neodymium and continuous CO_2 lasers were used. The laser beam heating was carried out using inert gases e.g., argon, helium and nitrogen. In the present work laser treatment involving the near-surface melting was examined for the following reasons: controlled surface melting and high speed solidification are currently utilized to obtain structures and properties of practical interest. Different laser parameters were used to obtain melt penetration depths from about 100 μm in the case of CO_2 laser melting and 500 μm in the case of neodymium pulsed laser melting. The schemes of laser treatment are presented in Figure 1.

After laser beam treatment the specimens were tempered at 500°, 600° and 700°C for a holding time of 2 hrs. Microstructural and compositional analysis consisted of optical, and transmission electron microscopy and wavelength dispersive X-ray microprobe and X-ray diffraction analyses. For optical and

scanning electron microscopy the samples were polished and etched electrolytically in 6% aqueous solution of CrO_3 at 8 V. Thin foils for transmission electron microscopy were prepared according the standard procedure and examined in a JEM-100B and Philips 400 operated at 100 kV and 120 kV.

Spectroscopy was done using microprobe CAMECA operated at 20 kV. The point quantitative, linear and surface distribution analysis were used. X-ray diffraction analyses were carried out using a Kristalloflex 4W X-ray generator and CoK_α radiation. Microhardness was determined using a Hanemann microhardness tester.

III. Results and Discussion

Figures 2 a-f show the optical electron scanning and electron transmission microscopy of cross-sections in the plane parallel to the heated surface of the laser-treated T1 steel. Figures 2 a, b, c show the structure in the zones treated by the neodymium pulsed laser and Figures 2 d, e, f in the zone treated by the CO_2 laser.

It was observed that the structure in the neodymium pulsed laser treated zones was acicular martensite with a small amount of retained austenite and M_6C carbides. The carbide particles which were observed in these zones were residues of large undissolved carbides. At higher magnification, the zones glazes by CO_2 laser display a three phase structure i.e.: large-grained matrix (martensite and retained austenite), these being generally oriented normal to the external surface and a phase which is white at Figure 2 e and darker at Figure 2 f, segregated at grain boundaries. It was shown by electron and X-ray examinations that this is M_6C carbide (see Figures 4-8). Figure 3 (a-e) show a very interesting structure which was observed in pulsed laser-melted zones near the boundary with the unmelted matrix. In this region

rates of cooling are very much higher, and the resolidified structure is extremely fine. Microdiffraction in this region revealed ring patterns typical for polycrystals (see Figure 3 b). In the center of the melted zone acicular martensite was observed and the microdiffraction no longer has a ring pattern character (see Figure 3 e). The diffraction pattern and structure which were formed in the zones melted by the CO_2 laser are shown in Figure 3 h. The pattern is not polycrystalline. Figures 4 a-f show the microstructures by optic, electron scanning and electron transmission microscopy in the pulsed laser-melted zones. Figures 4 a, b and c are without tempering and Figures 4 d, e, and f are after 2 hrs tempering at 700°C.

The structure of zones after pulsed laser-melting is acicular without precipitation on the grain boundaries (see Figure 4 c). After tempering at 600°C and 700°C a very regular large ill-defined net of acicular precipitations (see Figure 4 d) and a fine net of carbides (see Figures 4 e, f) was observed. Figures 5 a, b, c show a typical TEM view of a pulsed laser melted region tempered at 700°C for 2 hrs. The cellular structure of precipitates was observed. They were identified as M_6C carbides by bright and dark field imaging and the corresponding selected area diffraction analysis. This was supported by EDS analysis. Figure 6 shows typical spectra obtained from EDS (using Philips 400 TEM). The spectra show a higher concentration of carbide-forming elements like V, Cr and W in the grain boundary compared to the centre of grains. The X-ray examinations, e.g., Figures 7 and 8 showed that in the CO_2 laser glazed zones the quantity of retained austenite was higher than in the pulsed laser-melted zones. Also, the quantity of retained austenite in the CO_2 laser-melted zones with nitrogen atmosphere was higher than that with helium atmosphere (see Figure 8 a, b). The reason for this is that

nitrogen, which was probably absorbed very quickly when the surface was permitted to melt, stabilized the austenite. Studies of the chemical composition of the laser-melted zones have shown that the neodymium laser-melted zones were very homogeneous (Figure 9) and the concentration of alloying elements (Cr, V, W) corresponds to their average concentration in the steel. The distribution of the elements in the CO_2 laser-melted zones (Figure 10) was not homogeneous because Cr, V and W were segregated during solidification in the interdendritic region where the M_6C carbides were nucleated.

The degree of non-uniformity in the distribution of elements in the laser-melted zones and in the matrix has been determined from the equation:

$$W = \frac{S_c}{\bar{c}}$$

where: S_c - standard deviation from mean value,

$\bar{c}$ - mean value of element concentration.

Concentration of Fe, W, V and Cr were measured at appr. 150 random points on the laser-glazed zones and on the matrix.

The following values of W were obtained:

Elements	W		
	on pulsed glazed zones	on CO_2 glazed zones	on matrix
Fe	0,17	0,40	0,55
W	0,10	0,52	0,71
V	0,12	0,44	0,62
Cr	0,09	0,35	0,43

The hardness profiles of the laser-melted and conventionally treated matrix (Figure 11) show that microhardness of laser-glazed zones which was less at first than microhardness of the matrix increases with temperature of tempering (as a result of the precipitation of phases shown in Figures 4 d, e, f and 5 while microhardness of the matrix decreases. Consequently after tempering at 700°C, the microhardness of the laser melted zones has a level of about 1000 μHV and the matrix about 550 μHV. This fact accounts for the higher resistance to wear for laser-treated knives in comparison to knives which have been conventionally heat treated.

IV. Conclusions

It has been shown that rapid chilling of T1 steel after laser melting gives rise to a variety of interesting and potentially useful metallurgical microstructures. The structure which was obtained by pulsed laser melting was an extremely fine acicular martensite with a small amount of retained austenite and undissolved carbides. The high chemical homogeneity was characteristic for this structure. The lower cooling rates after CO_2 laser melting compared to laser pulsed treatment contributed to obtaining a coarse structure which contained martensite, retained austenite and M_6C carbides precipitated as a network in the interdendritic region. In this case a high segregation of Cr, V and W was also found in the interdendritic regions. Results on similar steels namely M-2 and M-50 by Strutt and Nowotny[4], Kear, Breinan and Greenwald[5], Sare and Honeycombe[7], Niewiarowski, Matyja[9], showed that in the laser-melted structure M_6C carbides, austenite and 55% of ferrite δ but no martensite were present. In addition to X-ray diffraction and similar tempering behaviour to hardened steel give evidence that the material was martensite. Perhaps the

differences in interpretation of these structures is due to differences in the sources of heating and consequently in the size of melted zones. Strutt and Nowotny[4] and Kear, Breinan and Greenwald[5] used CO_2 laser of 3 kW power. In this research lasers of 150 W (CO_2 laser) and 7 J (neodymium pulsed) were used. To get a large heat treated surface the lasers were programmed to scan the surface of the specimens in successive spots or passes (see Figure 1). The second laser spot (or pass) affects the microstructure and properties of the prior pass. This is probably the reason for these differences in structure. But on the other hand our results are similar to those of Åhman.[8] Åhman has characterized the microstructure obtained after laser surface melting of M2 high speed steel as fully martensitic with a small amount of austenite and the regions of dark contrast in TEM (such as in Figures 2f, 3f and 5 in paper) here interpreted as an area of increased carbon and other alloying elements, giving rise to internal stresses. We have shown (using EDS) that there is an increase in V, Cr and W and probably C in the grain boundary (see Figure 6). Also we have identified this as M_6C carbides by bright and dark field imaging and selected area diffraction analysis (see Figure 5c). An increasing of microhardness in laser melted zones with temperature of tempering was observed as a result of precipitation. After tempering at 700°C, the microhardness of these zones was about two times higher in comparison to that of the matrix.

ACKNOWLEDGMENTS

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REFERENCES

1. J. Mazumder: J. Metals, May 1983, pp. 18-26.

2. J. D. Ayers: J. Metals, Aug. 1981, pp. 19-21.

3. J. J. Rayment, B. Cantor: Met. Sci., 1978, vol. 12, pp. 156-163.

4. P. R. Strutt, H. Nowotny, M. Tuli, and B. H. Kear: Mat. Sc. Eng., 1978, vol. 36, pp. 217-22.

5. B. H. Kear, E. M. Breinan, L. E. Greenwald: Met. Techn., Apr. 1974, pp. 121-129.

6. J. Kusinski, R. Krehlik, Z. Gredys: Patent nb. P.23834SB23K.

7. I. R. Sare, W. K. Honeycombe: Met. Sci., 1979, vol. 73, pp. 269-279.

8. L. Åhman: Metall. Trans. A., 1984, vol. 15A, pp. 1829-35.

9. J. Niewiarowski, H. Matyja: 3rd International Conference, Rapidly Quenched Metals (1978), London.

FIGURE CAPTIONS

Fig. 1. Schematic diagrams of laser-heat treatment: (a) pulsed laser heating; (b) CO_2 laser heating. T_t = melting temperature.

Fig. 2. Metallographic structure: optical (a-d); electron scanning (b,e); and electron transmission (c,f) in plane parallel to surface of laser-treated T1 steel. a,b,c - in neodymium laser melted zone. d,e,f - in CO_2 laser melted zone.

Fig. 3. Metallographic structures: optical (a) and electron transmission (b-f) and electron diffraction patterns in neodymium laser-melted zone (d-e) and in CO_2 laser-melted zone (f).

Fig. 4. Metallographic structures (optical - a,d; electron scanning - b,c,e,f) in the pulsed laser-melted zones (a,b,c - without tempering; d,e,f - after 2 hrs tempering at 700°C).

Fig. 5. TEM micrographs from pulsed laser-melted and 700°C tempered zone, a,b - typical microstructure view; c - bright and dark field imaging of $(442)_C$ and the corresponding selected area diffraction ($[011]_F$ and $[012]_C$ planes).

Fig. 6. Typical spectra obtained from EDS show concentration of V, Cr, Fe, W in the grain boundary and centre of trains in T1 steel after tempering of 700°C for 2 hrs. Cu-Kα peak is from system.

Fig. 7. X-ray diffraction patterns of the neodymium laser-treated and conventionally tempered steel.

Fig. 8. X-ray diffraction patterns of the CO_2 laser-treated steel with: a. nitrogen atmosphere; b. helium atmosphere; c. conventionally treated and tempered.

Fig. 9. Microstructure (a) and distribution of alloying elements in neodymium laser-melted zone (b,c).

Fig. 10. Microstructure (a) and distribution of alloying elements in CO_2 laser-melted zone (b,c).

Fig. 11. Changes of microhardness with temperature of tempering in neodymium laser melted zone, CO_2 laser melted zone and in the matrix.

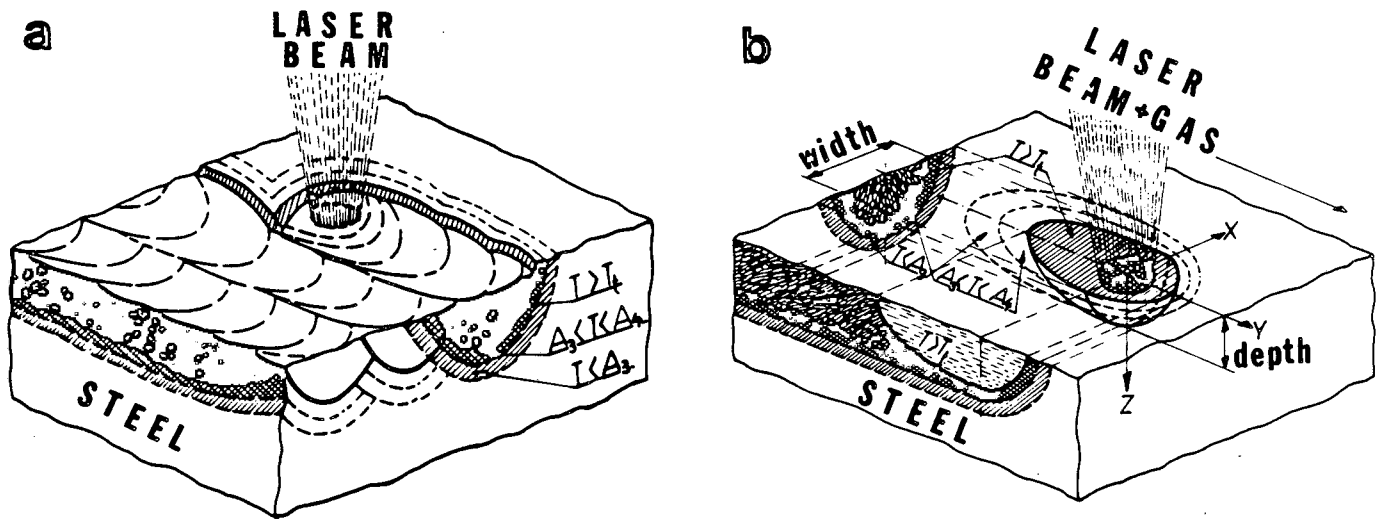

Fig. 1. Schematic diagrams of laser-heat treatment: (a) pulsed laser heating; (b) CO_2 laser heating. T_t = melting temperature.

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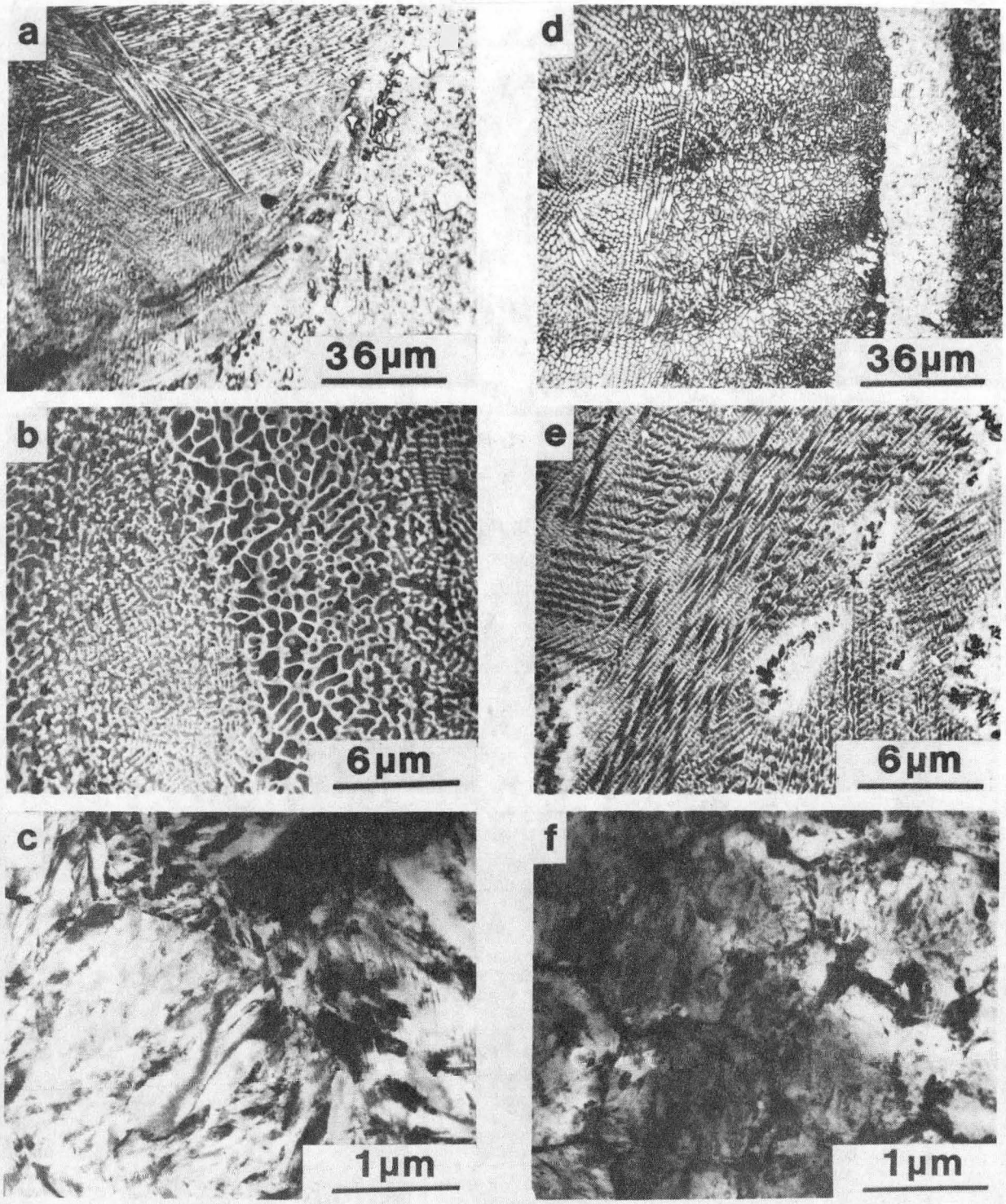

Fig. 2. Metallographic structure: optical (a-d); electron scanning (b,e); and electron transmission (c,f) in plane parallel to surface of laser-treated T1 steel. a,b,c - in neodymium laser melted zone. d,e,f - in CO_2 laser melted zone.

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Fig. 2

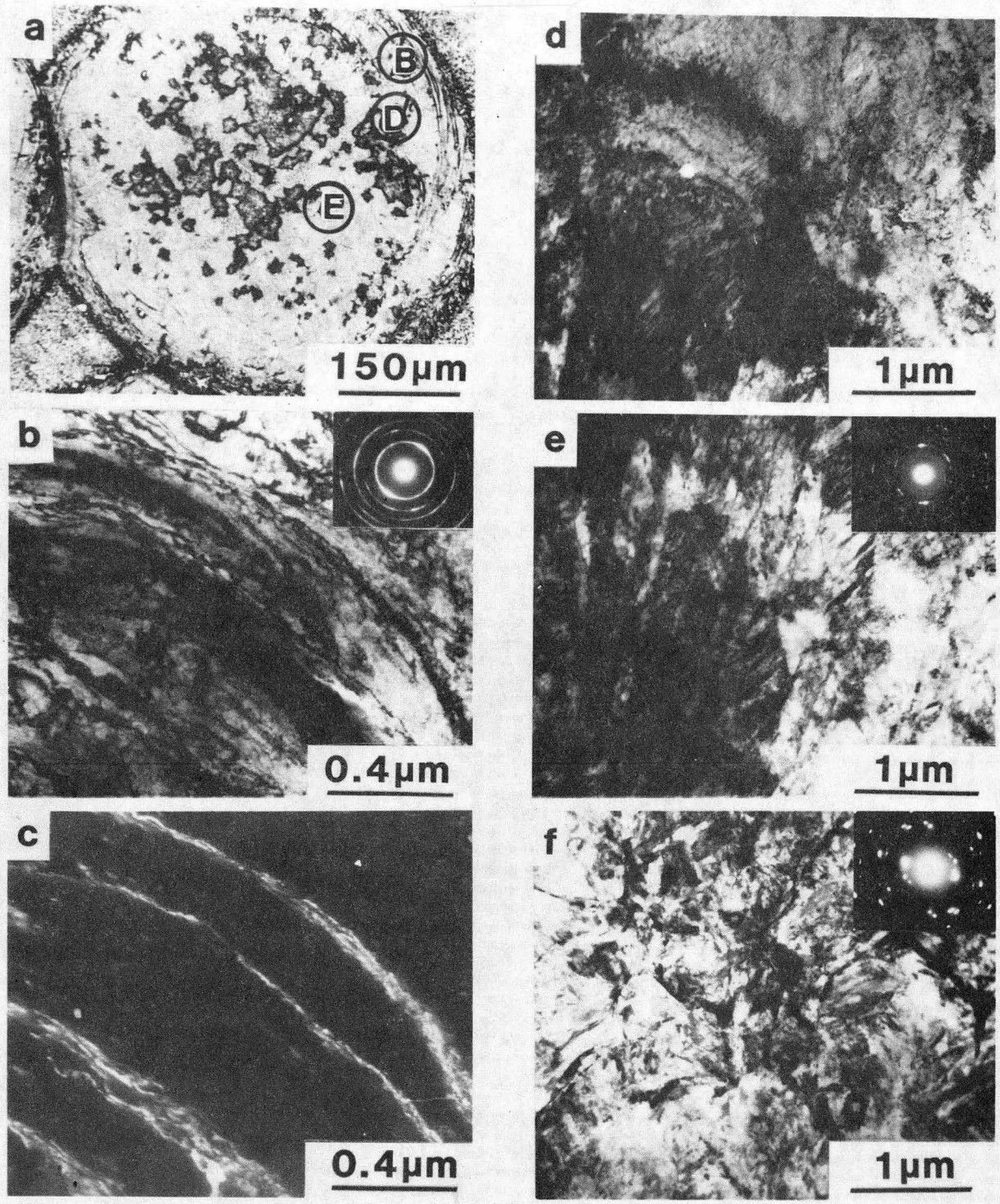

Fig. 3. Metallographic structures: optical (a) and electron transmission (b-f) and electron diffraction patterns in neodymium laser-melted zone (d-e) and in CO_2 laser-melted zone (f).

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Fig. 3

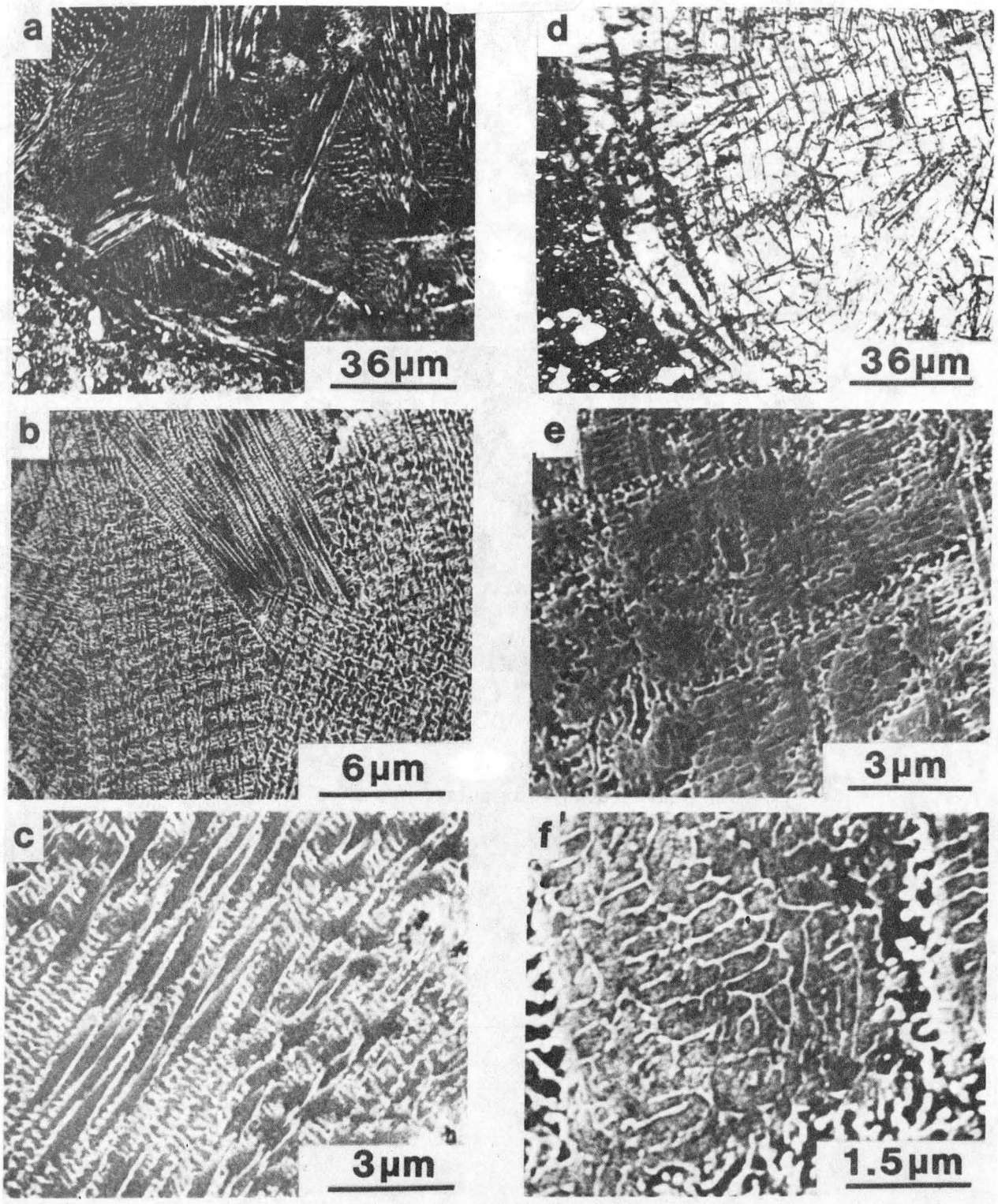

Fig. 4. Metallographic structures (optical - a,d; electron scanning b,c,e,f) in the pulsed laser-melted zones (a,b,c - without tempering; d,e,f - after 2 hrs tempering at 700°C).

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Fig. 4

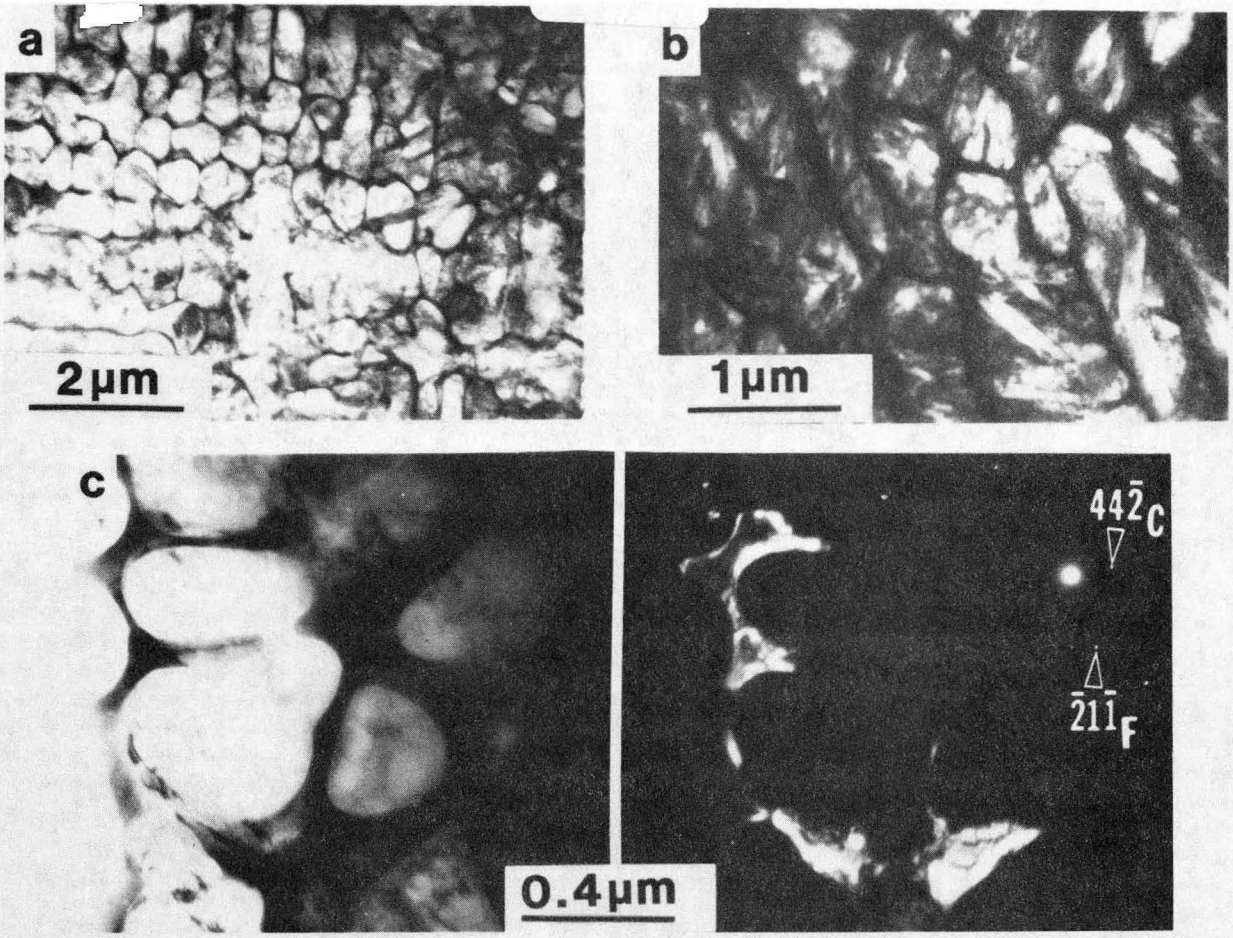

Fig. 5. TEM micrographs from pulsed laser-melted and 700°C tempered zone, a,b - typical microstructure view; c - bright and dark field imaging of $(442)_C$ and the corresponding selected area diffraction ($[011]_F$ and $[012]_C$).

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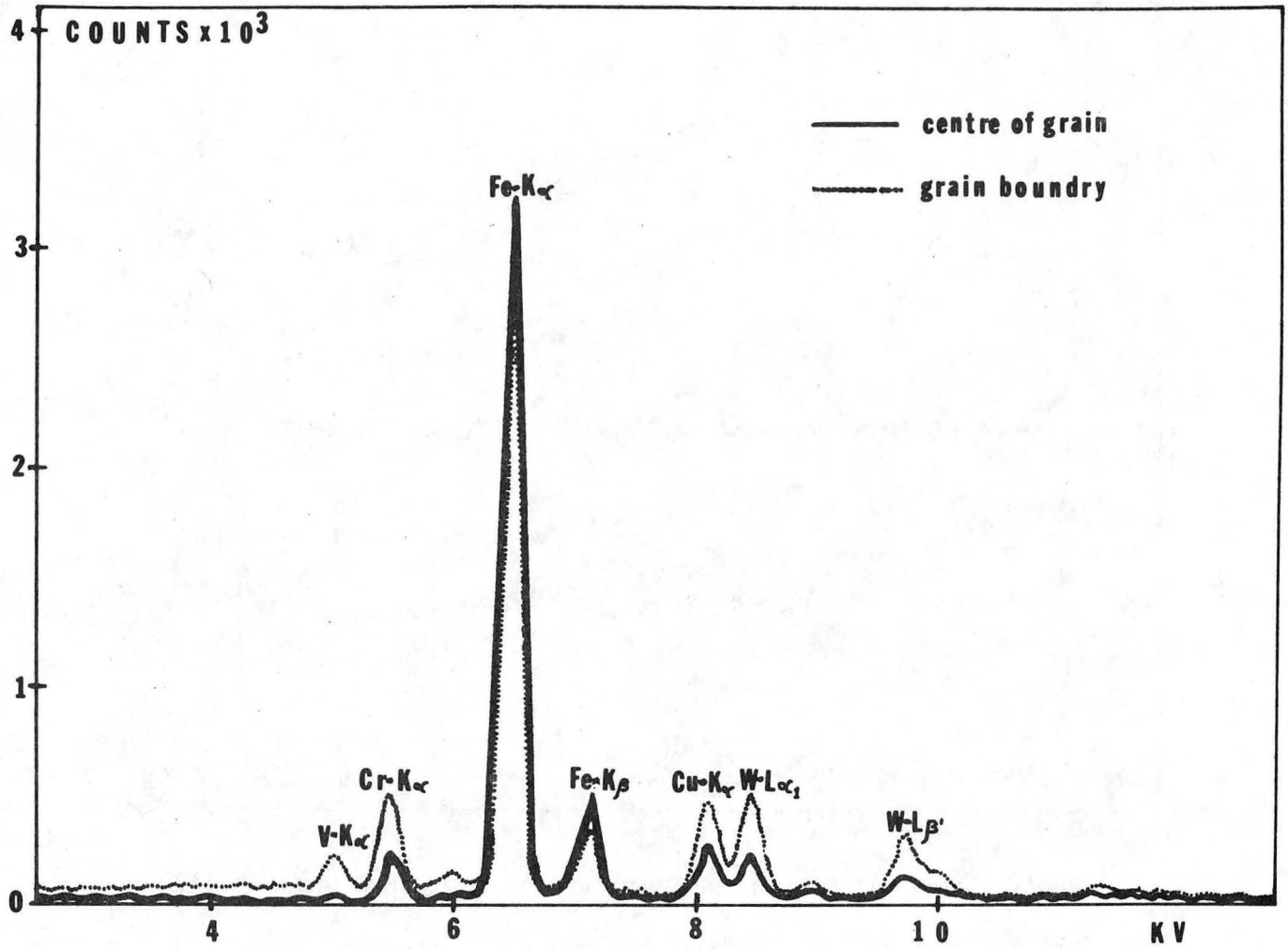

Fig. 6. Typical spectra obtained from EDS show concentration of V, Cr, Fe, W in the grain boundary and centre of trains in T1 steel after tempering of 700°C for 2 hrs. Cu-Kα peak is from system.

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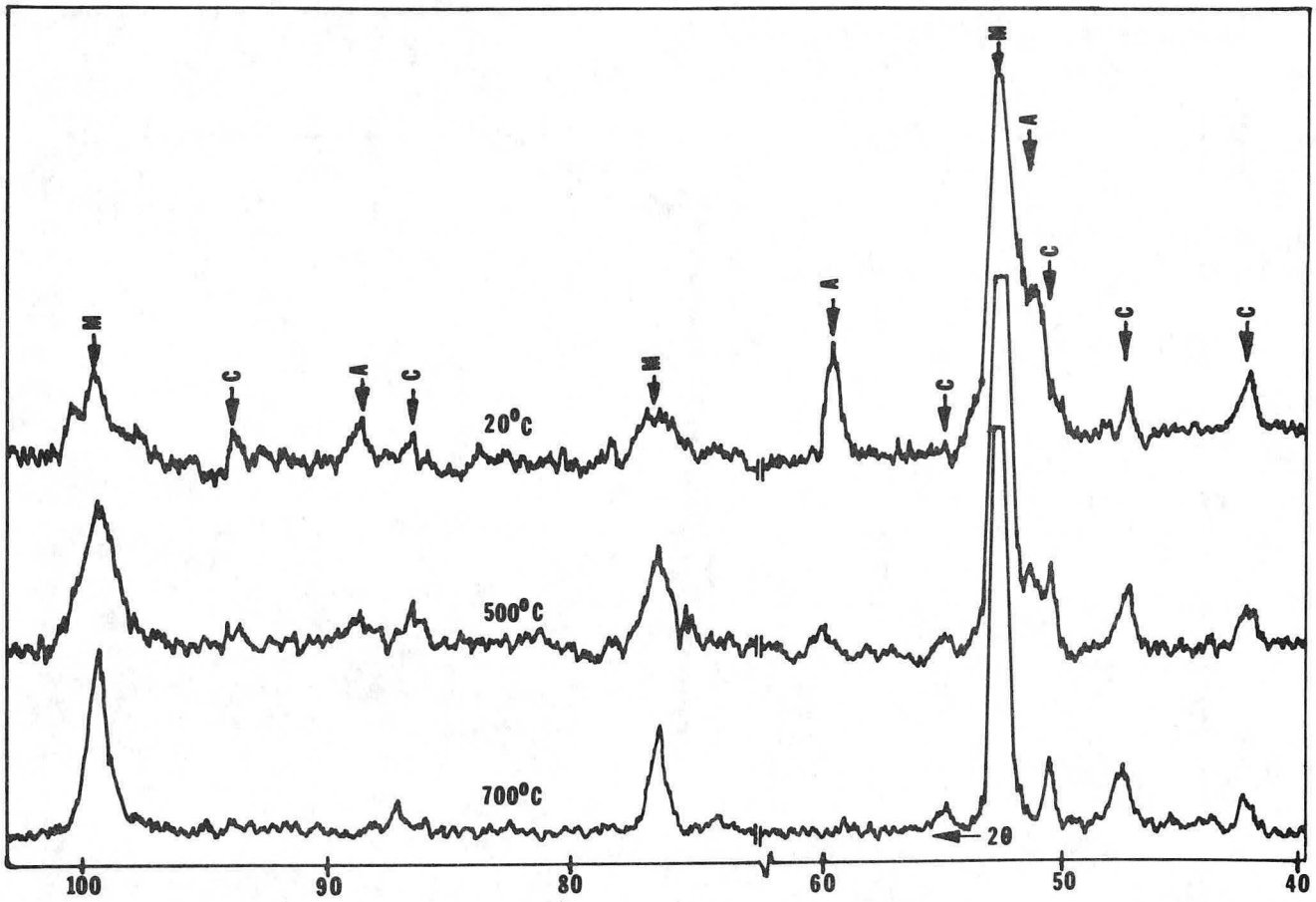

Fig. 7. X-ray diffraction patterns of the neodymium laser-treated and conventionally tempered steel.

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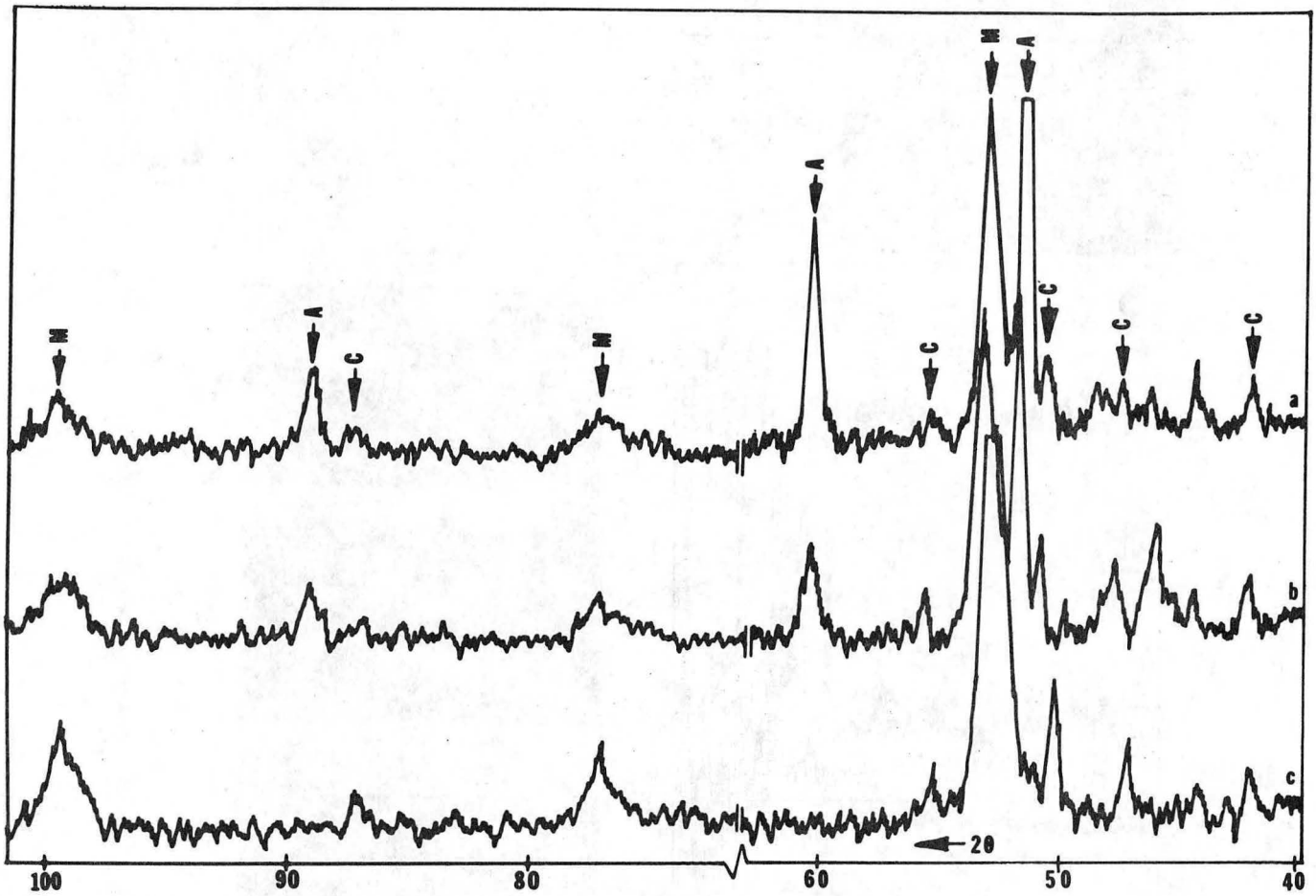

Fig. 8. X-ray diffraction patterns of the CO_2 laser-treated steel with: a. nitrogen atmosphere; b. helium atmosphere; c. conventionally treated and tempered.

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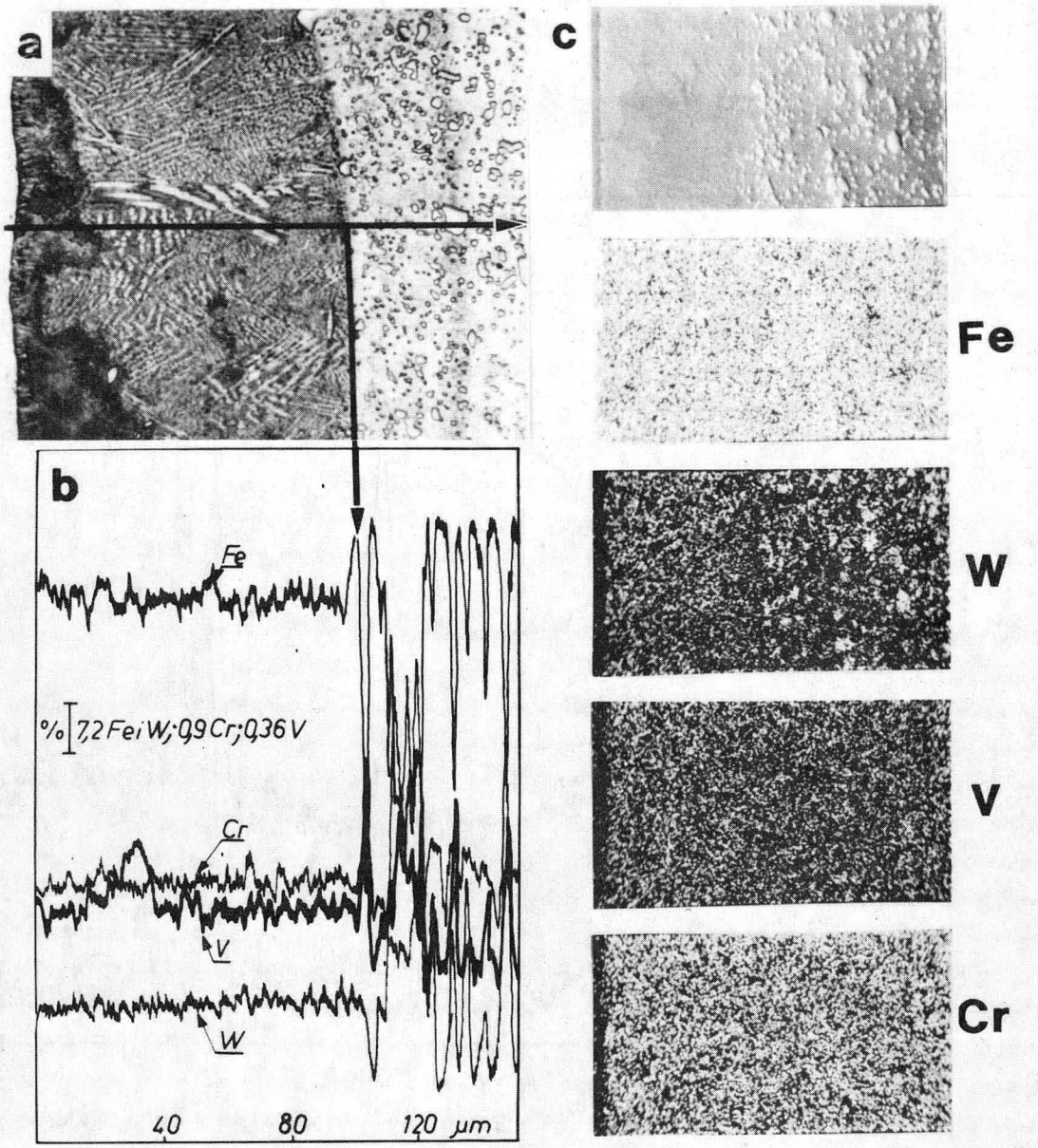

Fig. 9. Microstructure (a) and distribution of alloying elements in neodymium laser-melted zone (b,c).

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Fig. 9

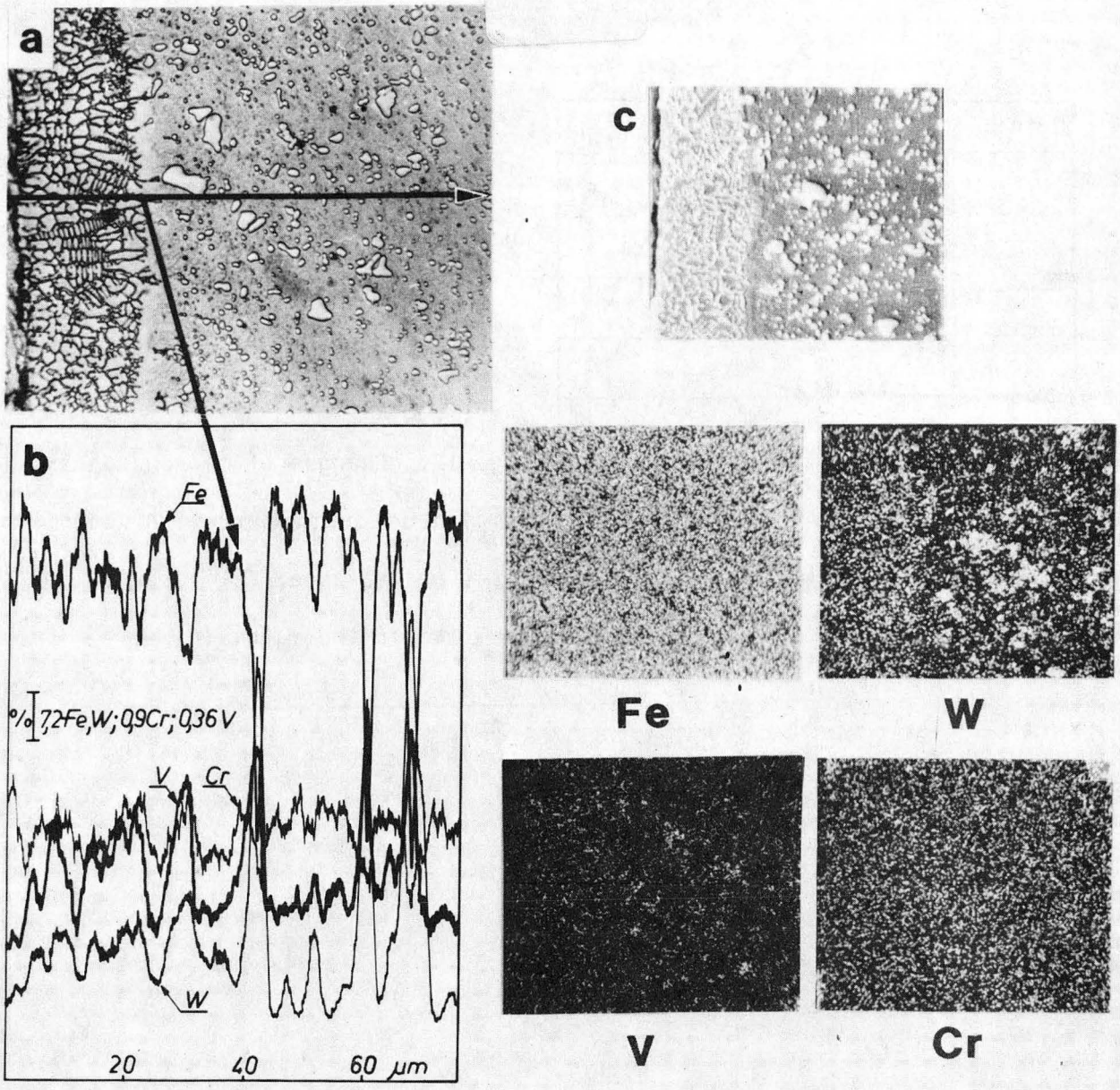

Fig. 10. Microstructure (a) and distribution of alloying elements in CO_2 laser-melted zone (b,c).

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Fig. 10

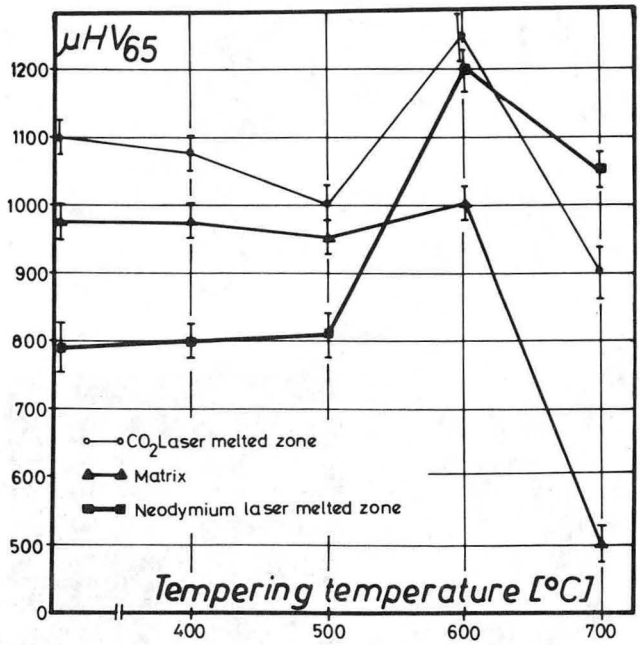

Fig. 11. Changes of microhardness with temperature of tempering in neodymium laser melted zone, CO_2 laser melted zone and in the matrix.

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Fig. 11

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