MECHANICAL PROPERTIES AND PHASE ANALYSIS EXPLOSIVELY WELDED Ti-Cr/Ni STEEL IN AS-RECEIVED STATE AND AFTER HEAT TREATMENT

Dmytro OSTROUSHKO[a], Eva MAZANCOVÁ[a], Karol SAKSL[b], Ondrej MILKOVIČ[c]

[a]*VSB-Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, Ostrava, Czech Republic, EU, dimitrij.o@seznam.cz, emazancova@vsb.cz,*

[b]*ÚMV-SAV, Kosice, Slovak Republic, EU, ksaksl@imr.saske.sk,*

[c]*Technical University Košice, Kosice, Slovak Repulic, EU, ondrej.milkovic@tuke.sk.*

Abstract

Surface coatings protection is one of the most important processes ensuring efficient and economic use of basic materials, mostly of lower-quality. At interface of clad and basic material intermetallic phases are formed, representing quite different matrix with dissimilar properties unlike the welded materials. One type of surface coating is explosive bonding which belongs to group of pressure welding. The work is focused on some mechanical properties, micro-hardness in-homogeneities in vicinity of the wave joint both in the basic material and nearby of the Ti and Cr/Ni stainless steel matrix weld line. Investigated weld was both in as-received state and after heat treatment carried out at 600°C/90 minutes/air. The TEM investigation includes a dislocation density and structures in both samples. Phase has been identified by X-ray diffraction performed by synchrotron radiation, and Tiα, Fe-fcc, Fe-bcc and Fe_2Ti intermetallic phases were detected at interface area.

Keywords: Ti-Cr/Ni, explosive bonding, interface area, heat treatment, hardness, phase analysis.

1. INRODUCTION

Explosive welding enables to joint directly a wide variety of similar or quite different metals that cannot be joined using any other welding or bonding techniques [1-3]. The bonded materials show higher strength, resistance to abrasion and corrosion, or toughness in the applied surface layer of material, whereas the whole product does not have necessarily to be made from the same material. Bonding methods also significantly reduce material costs. The mentioned bimetal can find an application e.g. in heavy chemical industry. Presented work is focused on Ti-Cr/Ni stainless steel sandwich and especially its interface and its closed neighborhood. Mechanical properties (micro-hardness) and phase composition of the investigated material has been determined.

By several authors microstructure and mechanical properties of some explosively welded metals and alloys combinations have been studies. Characterization of the as clad TI and basic material Mn-C was showed in work [4]. The primary interest of this work was focused on hardness and microstructure in the close vicinity of the interface and amplitude of typical wavy bonding zone. The work [5-7] reports results of investigation phase analysis of explosively welded titanium-MnC steel by EDAX. Just few information about the stainless Cr18Ni10 steel (SS)-titanium sandwich that is why the presented work is focused on some mechanical parameters and phase analyse after explosion bonding and after follow-up heat treatment (HT). In work [8] results of the chemical composition of titanium-SS sandwich interface using EDAX was presented, which are not quite accurate and do not show specific phase composition. For this reason, phase analysis using monochromatic synchrotron radiation an attention was paid.

2. EXPERIMENTS AND SOLUTION TECHNIQUE

In the study we examined Ti clad explosively welded on the Cr/Ni stainless steel. Titanium of commercial purity showed followed chemical composition (wt. %): 0.01C, 0.05Fe, 0.05O, 0.005N, 0.006H and the SS had

chemical composition (in wt. %) as it follows: 0.04C, 0.45Si, 1.96Mn, 18.42Cr, 9.74Ni, 0.065P and 0.011S. The used explosive welding parameters are in the range required for bonding and are know-how of Explomet comp. Samples of Ti and Cr/Ni SS sandwich were machined by mechanical cutting to avoid any change in microstructure. The thickness of Cr/Ni SS was 110 mm and the Ti layer corresponded to 6 mm (in sequence). For phase analyse samples of dimension 40 x 20 x 10 mm were cut from the bulk. Individual pieces were then embedded to poly-fast, then grinded (P300, P600, P800, P1200, P2500), polished in PHOENIX 4000, Buehler (grinding paste of 0.006 mm graininess with distilled water) and finally etched in KROLL (100ml H_2O + 6ml HNO_3 + 3ml HF) [9] for about 3 second. For TEM investigation mechanical samples thinning was carried out by electrolytic polishing in the electrolyte $HClO_4$ + CH_3OH at a temperature of -20 ° C and a constant potential of 22 V in the device TENUPOL - 5 (double jet).The investigated samples were in as-prepared state and after the HT. Applied HT was annealing at 600 °C for 1.5 h in a protective atmosphere followed by air cooling. In both samples microstructure was examined close to the interface.

For the micro-hardness tests micro-hardness machine LECO with diamond pyramid (Vickers) and low load (0.1 N) was used. The indents have been applied for Ti and Cr/Ni SS matrix across the bonding line area. The numbers of indents was 30 going from Ti (10 steps) across the Ti-Cr/Ni SS interface to Cr/Ni SS (19 steps) divided to 240 μm steps. **Fig. 1** demonstrates typical bonding line (interface) of the studied material. After the HT Ti-Cr/Ni SS sandwich shows wavy interface in nature as it was observed after explosive bonding [10].

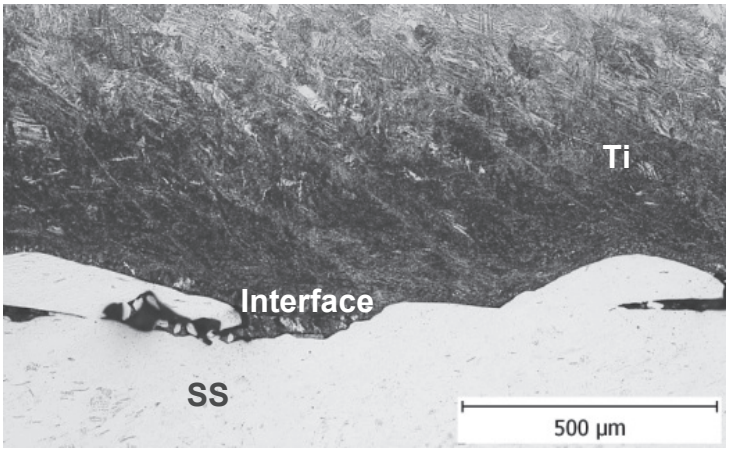

Fig.1 Typical wavy bonding zone Ti-Cr/Ni steel

The XRD measurements were carried out using the BW5 experimental station [11] located at the DORIS III positron storage ring (energy 4.45 GeV, current 140-100 mA) at HASYLAB/DESY, Hamburg, Germany. The energy of the incident beam was 100 keV, lambda corresponded to 0.124 Å. The specimen was scanned shot-by-shot along a path of total length of 40 mm with step width of 1mm. During each step, the sample was illuminated by highly intensive hard X-rays for 2 seconds. The resulting 2D XRD patterns were recorded using a Perkin Elmer 1621 detector. The collected data were then integrated into 2 Theta space by using the FIT2D software [12]. The sample-detector distance, detector orthogonality with respect to the incoming radiation, as well as precise radiation energy was determined by fitting a standard reference LaB6 sample [13].

3. RESULTS

Results of micro-hardness test are presented in **Fig. 2**, where blue line represents sample without the HT and the red line sample with the HT. In vicinity of the bonding line maximum values of hardness were detected in both materials (without the HT and after the HT). In Cr/Ni SS the hardness corresponded to 450 HV0.1, while in the Ti matrix to 180 HV0.1. The Cr/Ni SS showed 2.5 times higher hardness values than the Ti material. In Cr/Ni SS hardness difference was about 28 %, while in the Ti matrix practically none change after the HT was registered. These results confirm the more important changes were realised in the austenite matrix.

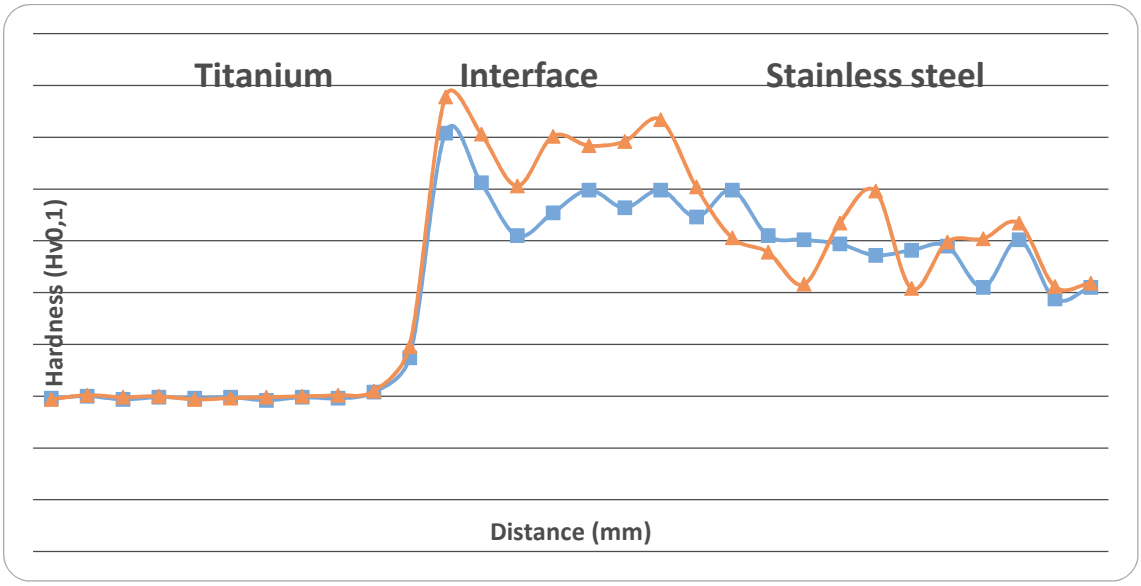

Fig. 2 Results of micro-hardness test

Figs. 3 and **4** represent substructures of stainless steel samples after welding explosion. Samples are in initial state and after the HT. These figures characterize the highly deformed structure with high dislocation density and the incidence of sub-grains and twins.

a) b)

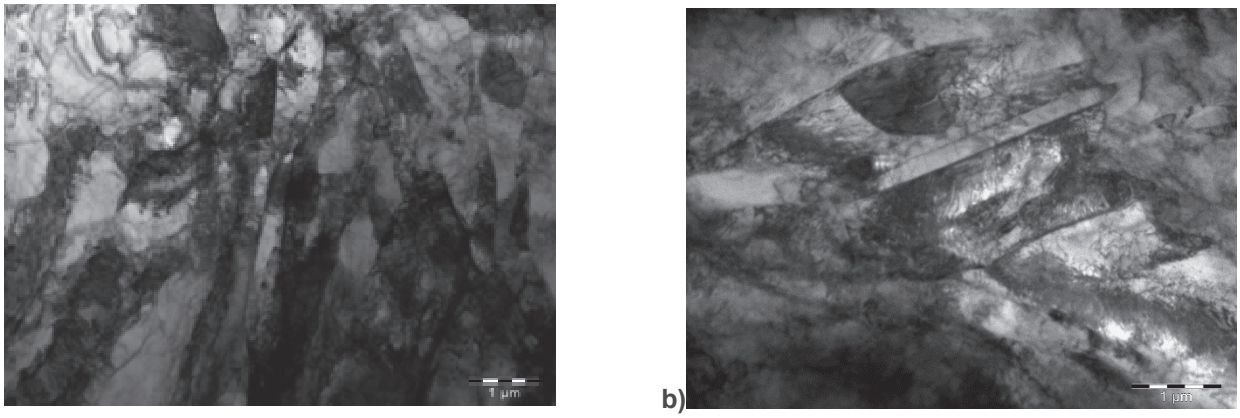

Fig. 3 Structure of stainless steel (TEM) a) without the HT, b) after the HT.

a) b)

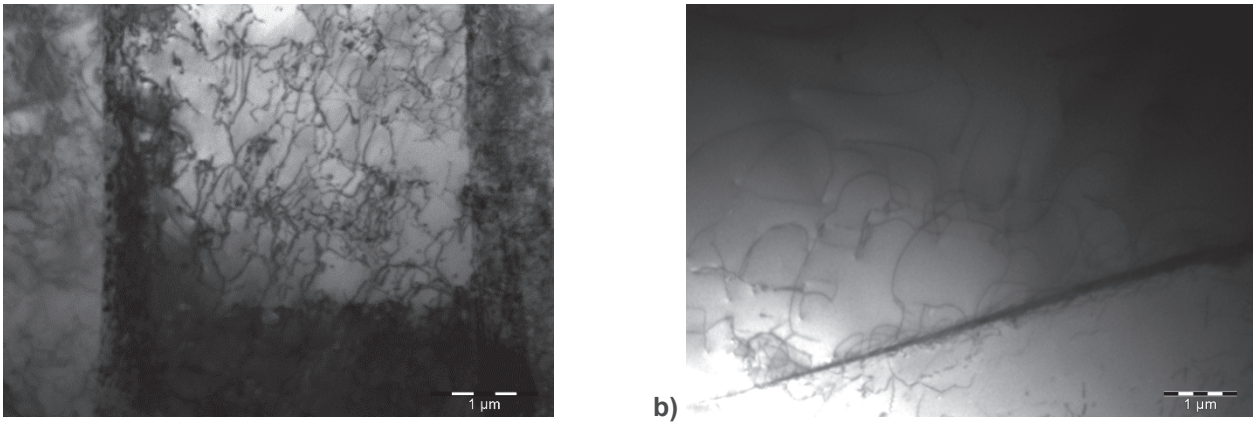

Fig. 4 Detail of stainless steel dislocation density I a) without the HT, b) after the HT.

Fig. 3 represents the structure of stainless steel after welding explosion and of subsequent HT process. In both cases microstructure showed high dislocation density and an appearance of sub-grains and twins, typical for deformation state produced by explosion. **Fig. 4** demonstrates a dislocation density in both samples. Microstructure of samples without the HT shows significantly higher level of dislocation density unlike the microstructure after the HT.

Fig. 5 shows 3D plot of obtained XRD patterns taken shot-by-shot going from the Cr/Ni SS to Ti. The picture clearly indicates abrupt change of the XRD pattern (roughly in the middle) corresponding to interface between these two materials.

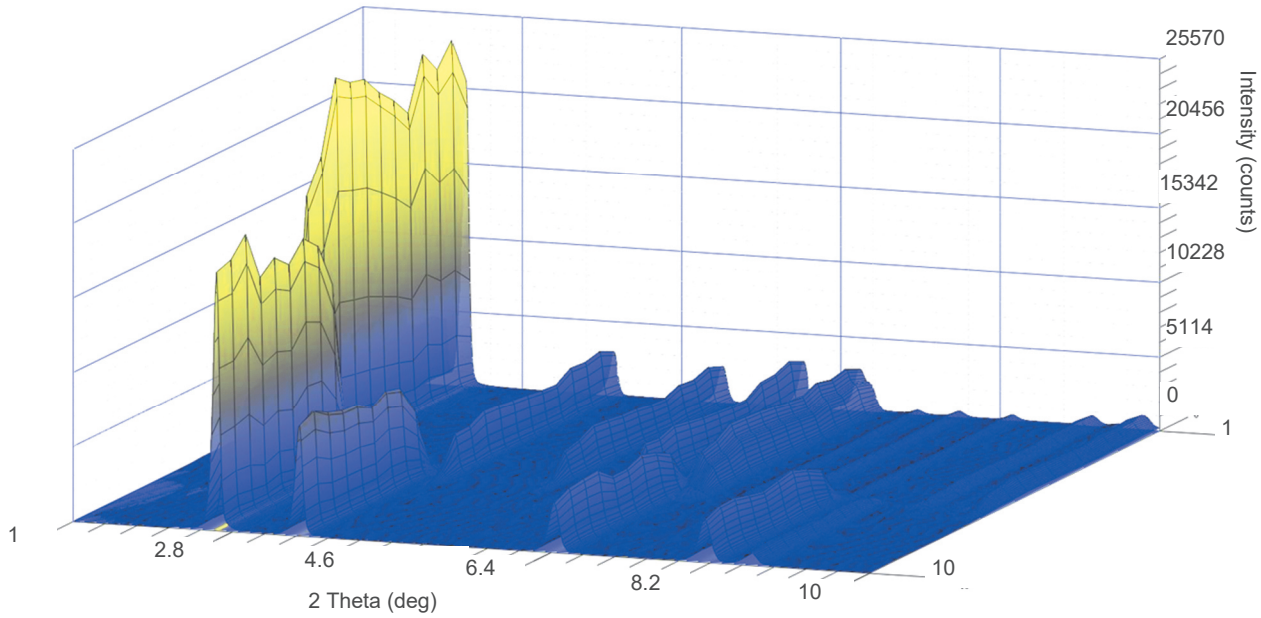

Fig. 5 3D plot of obtained XRD patterns of Ti-Cr/Ni SS bimetal

The XRD pattern from the interface region is shown together with patterns taken approximately 10 mm away from the interface in both directions (in Ti and to Cr/Ni SS) - see **Fig. 5**. Titanium consists of sole hcp-Ti alpha phase (S.G.: P63/mmc, a=2.95 Å, c= 4.6846 Å) and austenitic steel consists of fcc-Fe phase (S.G. Fm-3m, a= 3.599 Å). Interesting position is the interface region where mixing of this two phases is clearly visible. However, detail inspection of the pattern inclines to conclusion that there are few low intensive peaks (marked by the "**o**" sign - see **Fig. 6**) in addition coming from the third phase. All existing phases between Fe and Ti listed in ICDD PDF2 database [14] has been checked, but position of the peaks match up very well with pure bcc-Fe phase (S.G. Im-3m, a= 2.866 Å). Consequently, it can be stated the interface region probed in area 1x1 mm consists of the hcp-Ti, fcc-Fe solid solution, bcc-Fe like phases and Fe_2Ti intermetallic phases.

In samples after the HT, similarly as in samples without the HT, 10 mm from the joint towards to the austenitic steel the fcc-Fe phase was detected. In close vicinity of the bonding line mixture of alpha Ti phase and fcc-Fe bcc-Fe ferritic phase was observed (**Fig. 6**).

There are differences in the proportion of the fcc-Fe between the sample without the HT and after the HT. Sample after the HT shows significantly lower level (approximately by 60%, see diffraction maxima for images with "o" in **Fig. 6**). From that it can be concluded, deformation-induced austenite to ferrite transformation caused by explosion deformation can be reverted by appropriate HT. By going down from the interface to steel, the volume amount of the bcc-phase is rapidly decreasing, but 2 mm away from the interface it can be still

detected. Using this method Fe_2Ti intermetallic phases were detected in interface area, similarly like in work [8]. Those were detected by use of SEM technique.

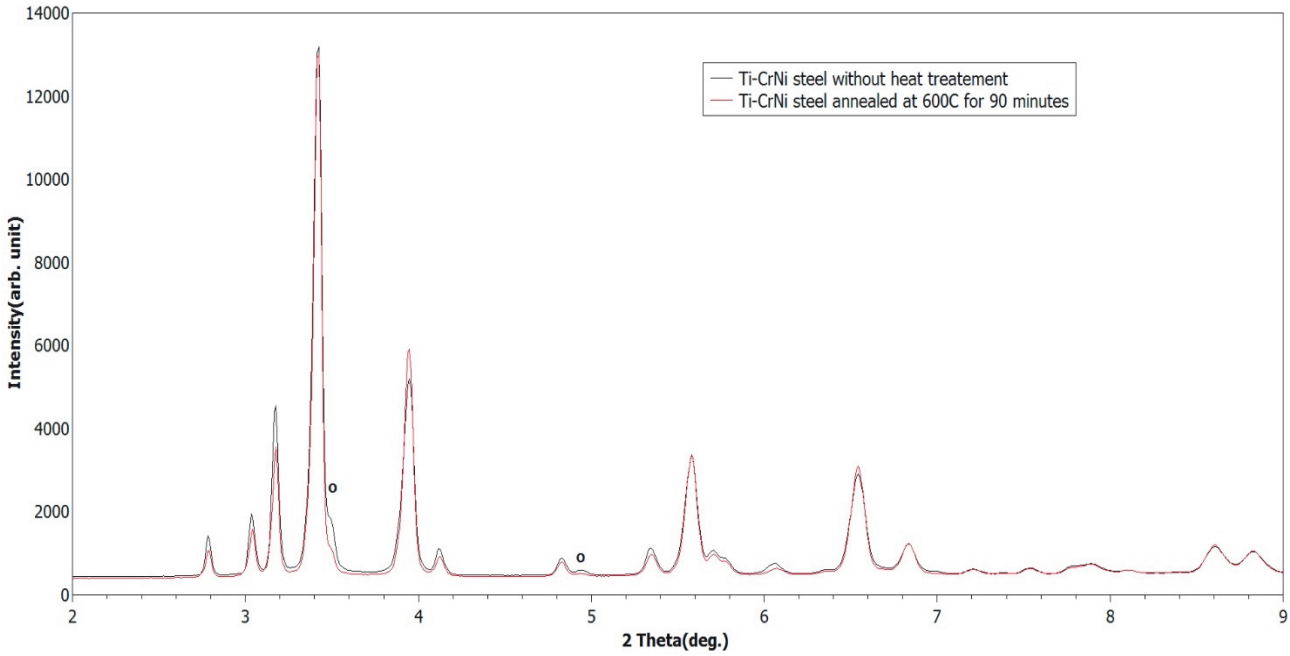

Fig. 6 XRD pattern from the interface area of Ti-Cr/Ni SS - compared materials without the HT and after the HT

CONCLUSION

The results could be summarized as follows: determination of micro-hardness revealed that at the interface deformation of materials occurred and was by 25 % higher in comparison to the Cr/Ni SS and by 300 % higher than in Ti. After the HT, in a localized area approximately 2 mm from the bonding line micro-hardness test showed hardness increase by 50 HV in the Cr/Ni SS.

The TEM investigation demonstrates differences in dislocation densities sub-grains and twins of microstructures of both samples. Samples without the HT show significantly higher level of dislocation density unlike the samples after the HT.

The XRD pattern showed that the interface region of both samples investigated in area of 1x1 mm consist of the hcp-Ti, fcc-Fe solid solution and bcc-Fe like phases. The sample after annealing at 600 °C/90 min/air shows significantly lower amount of the bcc-Fe phase. The intermetallic phases Fe_2Ti were detected at interface area by this method. Presented results and their deeper study will be part of next solution.

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REFERENCES

[1] BLAZYNSKI T.Z. Explosive Weldig, Forming and Compaction, the1st Ed.,Applied Science Publisher Ltd., London, 1983.

[2] LIMMERT G.E. Welding metalurgy-carbon and alloy steels, vol. 1 - Fundamentals, the 4th Ed., AWS, Miami, 1994.

[3] KROL S. Heat treatment of explosively welded bimetal. Overview of Welding, 43, 1991, 1-106 (in Polish).

[4] RAO N.V., SARMA D.S., NAGARJUNA S., MADHUSUHAN G. Influence of hot rolling and heat treatment on structure and properties of HSLA steel explosively clad with austenitic stainless steel, *Mater. Sci. Technol.*, 25, 2009, 138-139.

[5] SONG J., KOSTKA A., VEEHMAYER M., RAABE D. *Mat. Sci. Eng.,* A528, (2011) p.2641-2647.

[6] MOUSAVI S.A.A.A., AL-HASSANI S.T.S., ABKINS A.G. *Mater. Des.,* 29**,** 2008, 1334-1352.

[7] MOUSAVI S.A.A.A., SARTANGI P.F., *Mater. Sci. Eng.,* A494, 2008, 329-336.

[8] MAZANCOVÁ E., OSTROUSHKO D. Hydrogen response of 304 SS and Ti weld realized by explosion. , *Mater. Sci. Forum*, 782, 2014, 155-160..

[9] DANIELSON P., WILSON P., ALMAN D. Microstructure of titanium welds. Advanc. Mater. Process., 161, 2003,.39-42.

[10] OSTROUSHKO D., MAZANCOVÁ E., Chosen properties of sandwich material Ti-304 stainless steel after explosive welding. *Mater. Eng.*, 18, 2011, 8-10.

[11] BOUCHARD R., HUPFELD D., LIPPMANN T., NEUEFEIND J., NEUMANN H.-B., POULSEN H.F., RÜTT U., SCHMIDT T., SCHNEIDER J.R., SÜSSENBACH J., ZIMMERMANN M.J.*J. Synchrotron Radiat.*, 5, 2, 1998, 90-101.

[12] HAMMERSLEY A.P., SVENSSON S.O., HANFLAND M., FITCH A.N., HÄUSERMANN D. Two-dimensional detector software: from real detector to idealised image or two-theta scan. *High Press. Research.,* 14, 1996, 235-248.

[13] *NIST Standard Reference Material*, SRM 660a.

[14] *JCPDS-ICDD, PCPDFWIN*, 1998 (crystallographic database, version 2.0).