Vibration and Noise Analysis of Acetoxime Modified Tio_2 Coating Over Steel Alloy

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Abstract

In this research work, conventional gun spray method is used to coat oximemodifiedtitanium(IV) isopropoxide on steel to find out damping behaviour of coating. The most conventional method is modal analysis is used to measure vibration and noise damping of bare and titania coated samples. Test results revealed that a thin coating has improved the vibration and noise damping when compare with bare sample. SEM, EDX and AFM analysis were carried out to study morphology, coating thickness and composition of coating on the sample surface.

1. Introduction

The failure of metal structured components is commonly caused by metallic vibration. To overcome vibration, high damping materials and protective coatings are widely used in aircraft, ship and other dynamic system.[1–6] In dynamic systems, such as aircraft, gas turbine engines blades, ships and many load carrying structures typically operate under high pressure, temperature and shock [7] In such conditions, they are exposed to vibrations that reduce the service life of metals and alloys [8]. Many metal oxide coatings show promising results in such structures by improving their damping that help in reducing vibration and increases the service life of the structure.[9–14]

Damping effects can be created either by the surrounding media or by internal frictions of metals. There are many reported methods to analyse and understand damping behaviour of the structures [15–20]. The most conventional method is modal analysis in which impact induced free vibration measured and analysed. The free vibration exhibits natural characteristics of the structure which include natural frequencies and damping. The characteristics depend on size, shape of the structure and also on the boundary condition around the structure. Another method is forced vibration, which can be performed under controlled conditions by application of time-dependent loads. The load induced forced vibrations come in two kinds: a harmonic response, when a periodic force is applied to the plate; and a transient response, when the applied force is not a periodic force. These vibrations are analysed to understand damping behaviour of the structures [21] Several studies in the past have reported on the vibration damping behaviour of materials, polymers and composites [22–24]. However, the reported literature on study of vibration damping behaviour of coatings, perticularly on metal oxide coatings are limited [9–12].

In view of above, Titania (TiO_2) coating could be the savier material for many state of the art applications due to its superior mechanical, protective and tribological properties, which is extensively studied and documented in literature. [25–27] However, the damping behaviour of titania coating is not yet fully explored in the reported literature. Therefore, in this paper, we deposited titania coating over Steel alloy by conventional gun spray method using oximemodified Titania (IV) Iso-propoxide as a sol-gel precursor. Modal analysis is performed on the coated sample to investigate the effect on natural frequency and their damping characteristics due to titania coating. The morphology of coated surface is also analysed by using SEM and AFM studies.

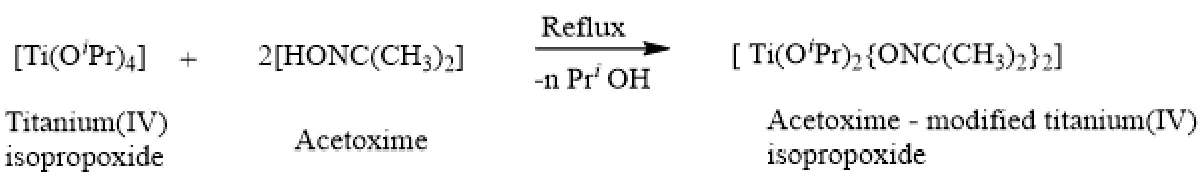
2. Materials And Methods

The composition of the steel sample used is as follows (wt. %): 9.98 Cr, 2.68 Mo, 1.45 Mn, 0.58 Si, 0.54 Ti, 0.49 Cu, 0.32 Co, 0.24 V and remaining 83.72 Fe. Steel samples having size 50 cm X 30 cm X 3 mm were polished by the reported methods before titania film deposition [25].

The morphology and thickness coated samples were studied by Field Emission Scanning Electron Microscopy (FE-SEM) using a Carl Zeiss EVO18 microscope. The roughness of coating determined by atomic force microscopic (AFM) analysis, performed on Bruker Multimode 8HR microscope. Vibration and noise damping experiments were carried out on custom made Brüel & Kjaer :- Impact hammer type 8206-001 having sensitivity 11.4mV/N, piezoelectric charge accelerometer type 4384, data acquisition module LAN-XI type 3050- A-060 with 6 channel inputs, PULSE Lab Shop’s 7700, Modal exciter (Type 4824) with a force rating of 100 N, Microphone Type: 4189-A-02.

2.1. Synthesis and characterization of titania sol

The oxime-modified titanium(IV) isopropoxide was synthesized by the reported method. [29] Titanium(IV) isopropoxide (2.000g) was added to the anhydrous benzene solution containg acetoxime (1.028 g). Reaction is maintained for 4 hours under refluxing (85°C) conditions. The acetoxime-modified titanium(IV) isopropoxide isolated after vaporization of solvent under vacuum conditions.



2.2. Deposition of titania coatings over Steel alloy

TiO_2 sol was prepared by acid hydrolysis of acetoxime-modified titanium(IV) isopropoxide using nitric acid and maintain the pH 3.5 [29]. Prior to coating, the samples were mechanically ground down upto 800, grit with silicon carbide (SiC) paper and then washed in ethonal to remove impurities. The TiO2 spray coating over the steel samples were performed by gun spray machine with following parameters: 04 cycles; spray distance: 15 cm; nozzle size: 0.7mm and sample position: 90°.

2.3. Vibration and noise measurement

Under controlled laboratory environment, modal testing of two different plates (i) bare steel plate (ii) Tio_2 coated steel plate was carried. The process is explained subsequently -

The setup shown above depicts rowing hammer test, conducted over the plates. Each plate (of size 50 cm X 30 cm X 3 mm) was marked according to the mesh of 10 x 20 so that each block measures 2 cm x 2 cm. The nodes (excluding the edges) were numbered from 1 to 171 in such a matter that 86th node became the center of the plate. The accelerometer was fixed at a strategic location inside the plate (Point

No. 71) to be able to capture the initial five modes of vibration. The plate was excited using the hammer at every other node on the plate (rowing hammer test) as shown in figure 1. For each excitation given, response function was obtained from the accelerometer readings. For indicative purpose, we have shown one of the frequency response function and the corresponding coherence function in figure 2. The peaks obtained in the Frequency Response Function (FRF) indicate modes of free vibration of the plate [15, 30]. Further, the coherence function attaining value of one (for almost the entire range of excitation) indicates the response function is reliable and good.

To verify the modal frequencies obtained from rowing hammer test, another test was conducted in which natural frequency of first mode of vibration was obtained using the modal shaker. In this setup, an additional modal exciter (shaker) was used to provide excitation at the center of the plate to excite first mode of vibration.

In this shaker test, to measure the the force of excitation provided by shaker, force transducer was installed in between the shaker and the plate. Further, accelerometer was strategically located very close to the shaker excitation since this region which have maximum acceleration in the first mode. The shaker was excited using the signal from the set of function generator and power amplifier. Force and acceleration was measured for various frequencies of excitation. Different frequency inputs were given to the setup in the vicinity of the first natural frequency obtained from impact hammer test. This helped in hunting down the first forced natural frequency of the plate. For each of the frequency input, the output of accelerometer and force transducer is noted in the form of the response ratio (ratio of acceleration and force).

3. Results And Discussion

3.1. Deposition of Alumina coatings on aluminum substrates and their characterization

The Tio_2 coatings were deposited on surface prepared steel alloy sample *via* spray gun setup using Tio_2 sol, prepared from acetoxime-modified titanium(IV) isopropoxide. Deposited Tio_2 coatings were sintered at 120ºC for 2 hrs and further characterized by SEM and AFM techniques**.** Compact, crack free Tio_2 coatings with thickness 4.146 μm to 4.527 μm observed in the SEM images of the coated samples shown in figure 4, 5.

Figure 6 shows high magnification SEM images and EDX spectra of bare and spray coated Tio_2 films on steel alloy. the presence of titania picks in grap 6b indicate Tio_2 coating over the steel alloy surface.

Figure 7 shows atomic force microscopy (AFM) micrograph of titania spray coated steel substrate. The R_a (arithmetic average deviation) and R_q (root mean square deviation) values obtained are 3.75 nm and 4.8 nm, respectively. The lower values indicating the possibility film are optically smooth and having lesser defects reported in the literatures [28-31].

3.2. Vibration and noise measurment

Natural frequency which is indicated by the location of the peak and damping which is indicated by the sharpness of the peak are recorded and compared for bare and Tio_2 coated Steel sample are listed down in table 1. We observed that damping has increased upto 2^{nd} mode of vibration after coating. Assuming the mass of the plate is constant, we can deduct that the stiffness has decreased. We obtained better damping values at each fundamental mode of vibrations for Tio_2 coated steel sample than the bare steel [18-19, 35-36].

We also plotted acceleration to force ratio at various input frequencies of excitation both types of samples and the observations are shown in figure 8. It can be observed that the coated plate gas lower natural frequency for first mode of vibration than that the bare steel plate. This again confirms our finding about the stiffness of the plate which is seen to be decreasing because of the coating assuming that the mass remains constant.

To understand the noise characteristics, we excited the bare and and Tio_2 coated steel plates with modal shaker at their fundamental mode of vibration. Noise level (figure 9) was measure for each experiment. We observed the peaks to be comparable for bare and coated samples which suggests that the coating does not have any identifiable impact on the noise characteristics of the alloy.

4. Conclusion

- A compact, crack free coating having thickness of ~ 4.146 μm a on steel sample were deposited by conventional spray method using titania sol, prepared by acetoximemodified titanium(IV) isopropoxide precursor.
- Damping capacity has improved in sample having coating thickness ~ 4.146 μm when compare with bare sample. Hence this material may be a candidate material for to be used in automobile, naval and sports applications where material minimization and improvement in damping capacity is required..

Declarations

Acknowledgment

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Tables

Table 1. Results of vibration measurements derived from frequency response function (FRF)

Mode Numbe	Bare Steel Alloy		Tio$_2$ Coated Steel Alloy	
	Frequency (Hz)	Damping (%)	Frequency (Hz)	Damping (%)
1	349.1	0.60	348.7	1.33
2	458.0	1.26	468.9	1.96
3	683.6	0.91	690.2	1.20
4	875.8	0.61	866.6	0.78
5	993.0	0.21	990.3	0.32

Figures

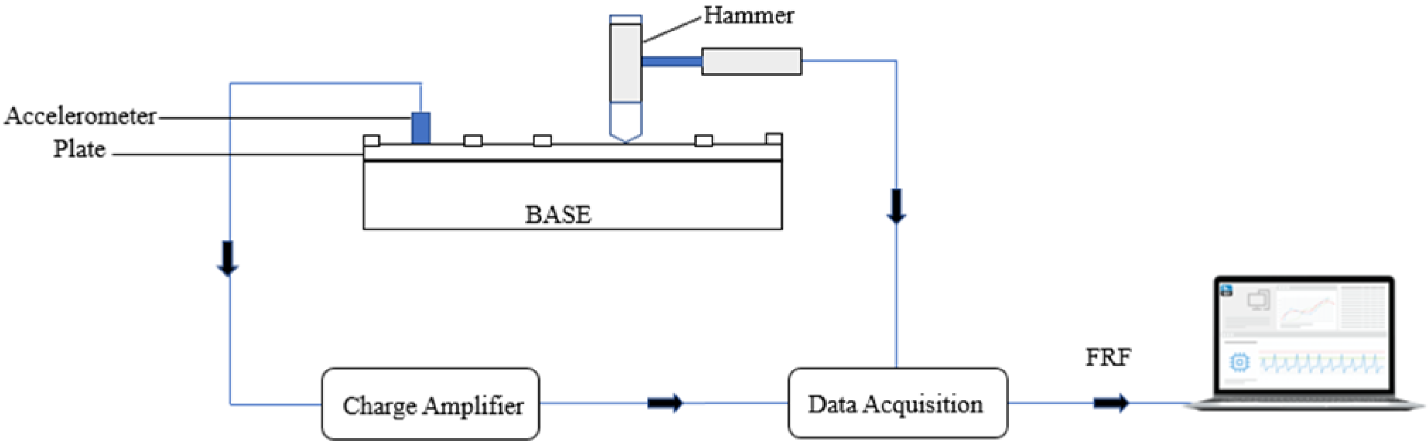

Figure 1

Hammer testing – schematic of the experimental setup

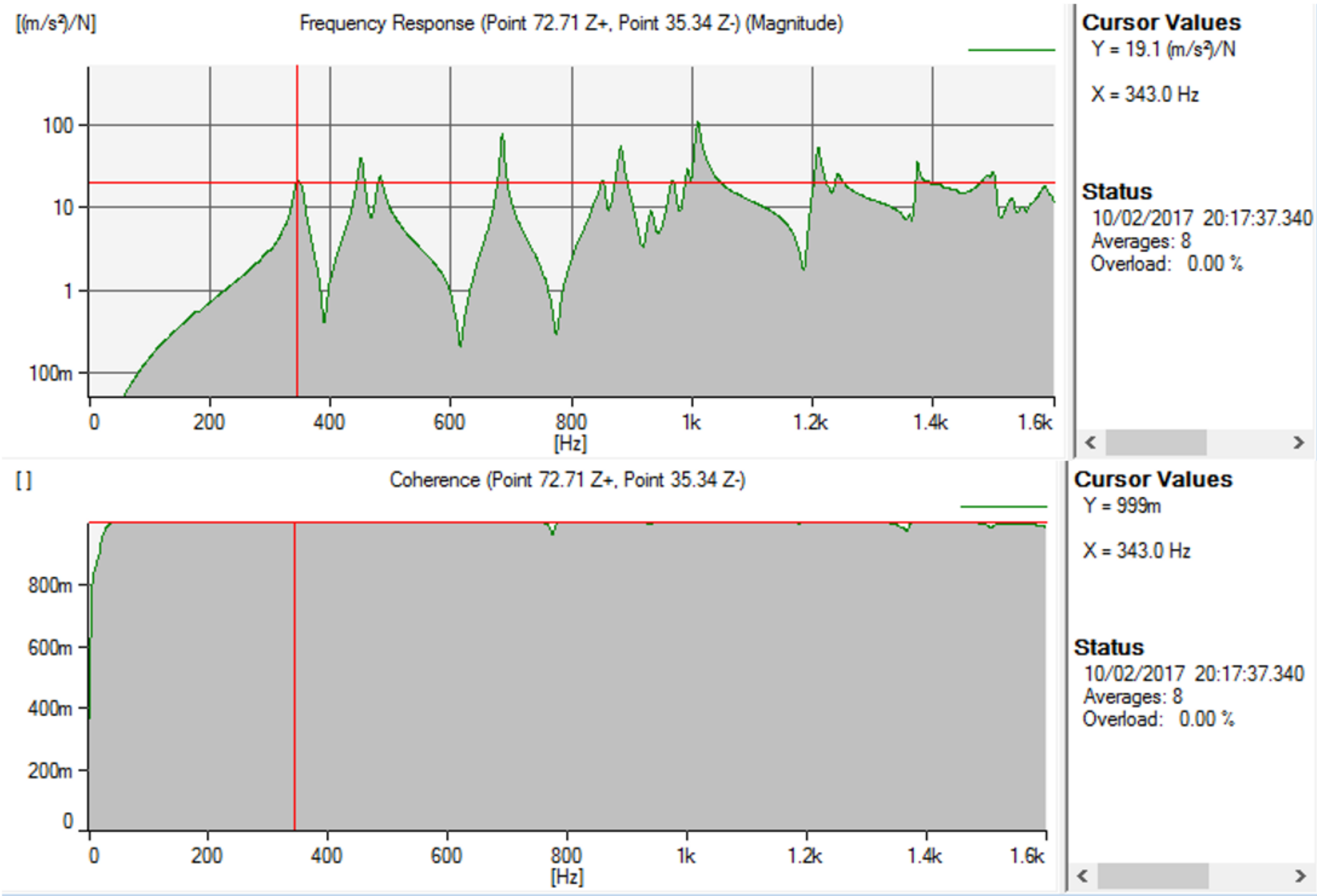

Figure 2

Response fuction indicating modes of vibration and coherence function inducating reliability of response function in impact hammer test for Steel alloy

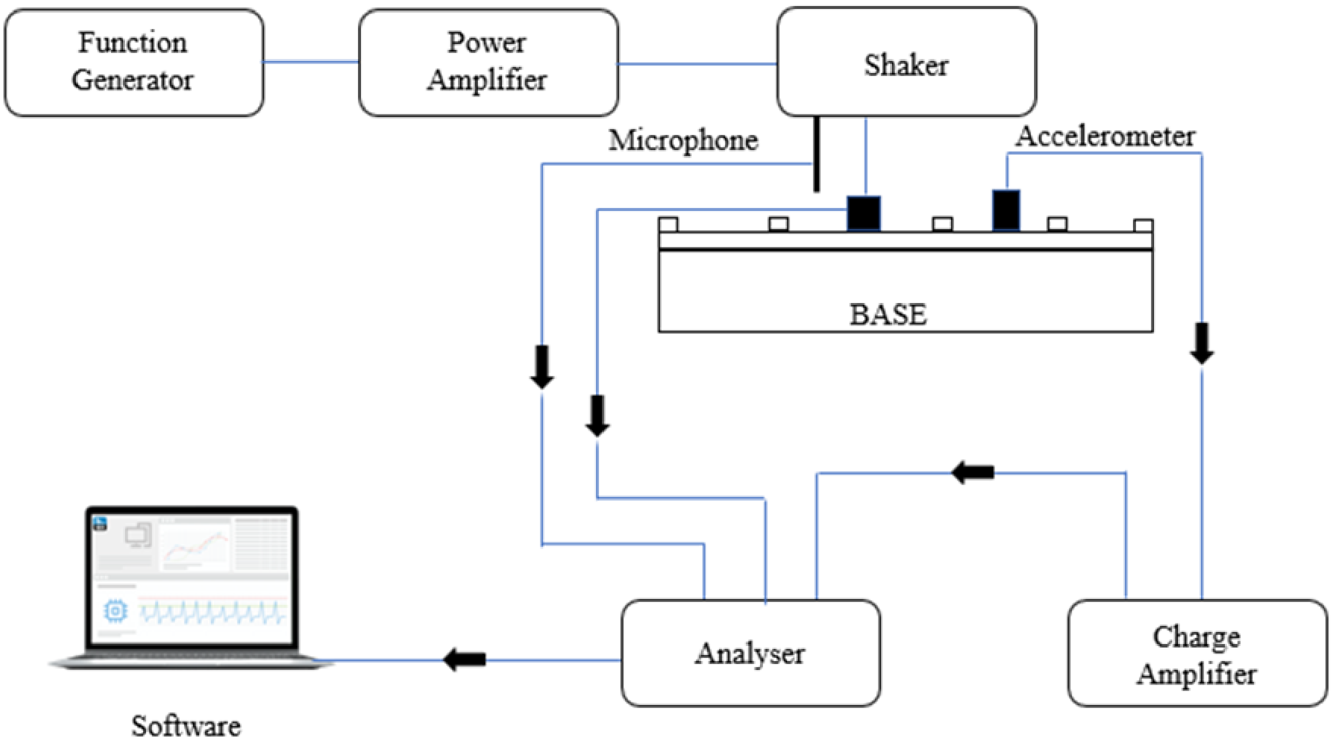

Figure 3

Shaker testing setup.

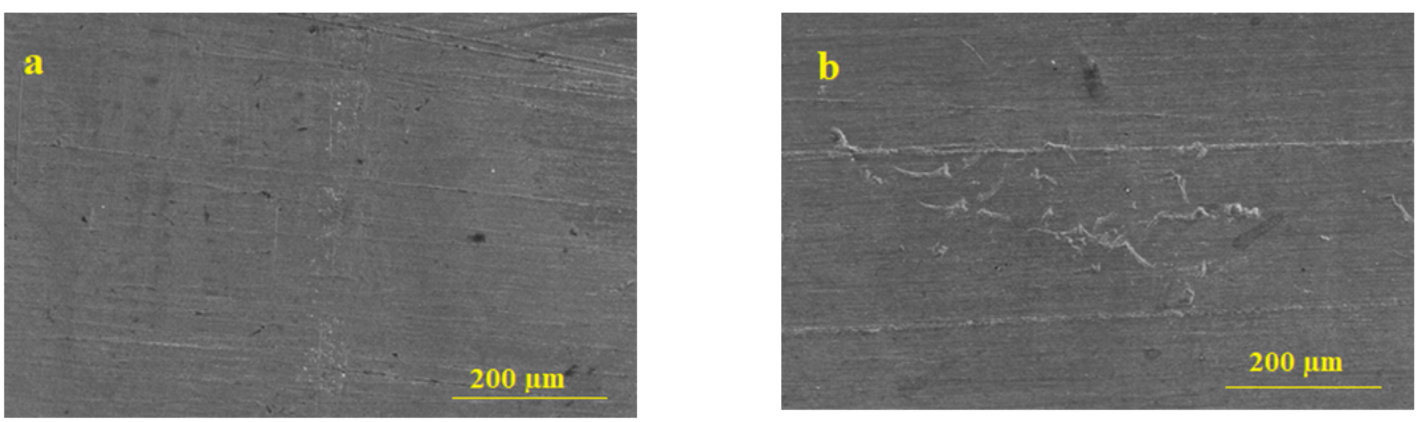

Figure 4

SEM images of (a) Bare and (b) Tio2 Spray coated Steel alloys

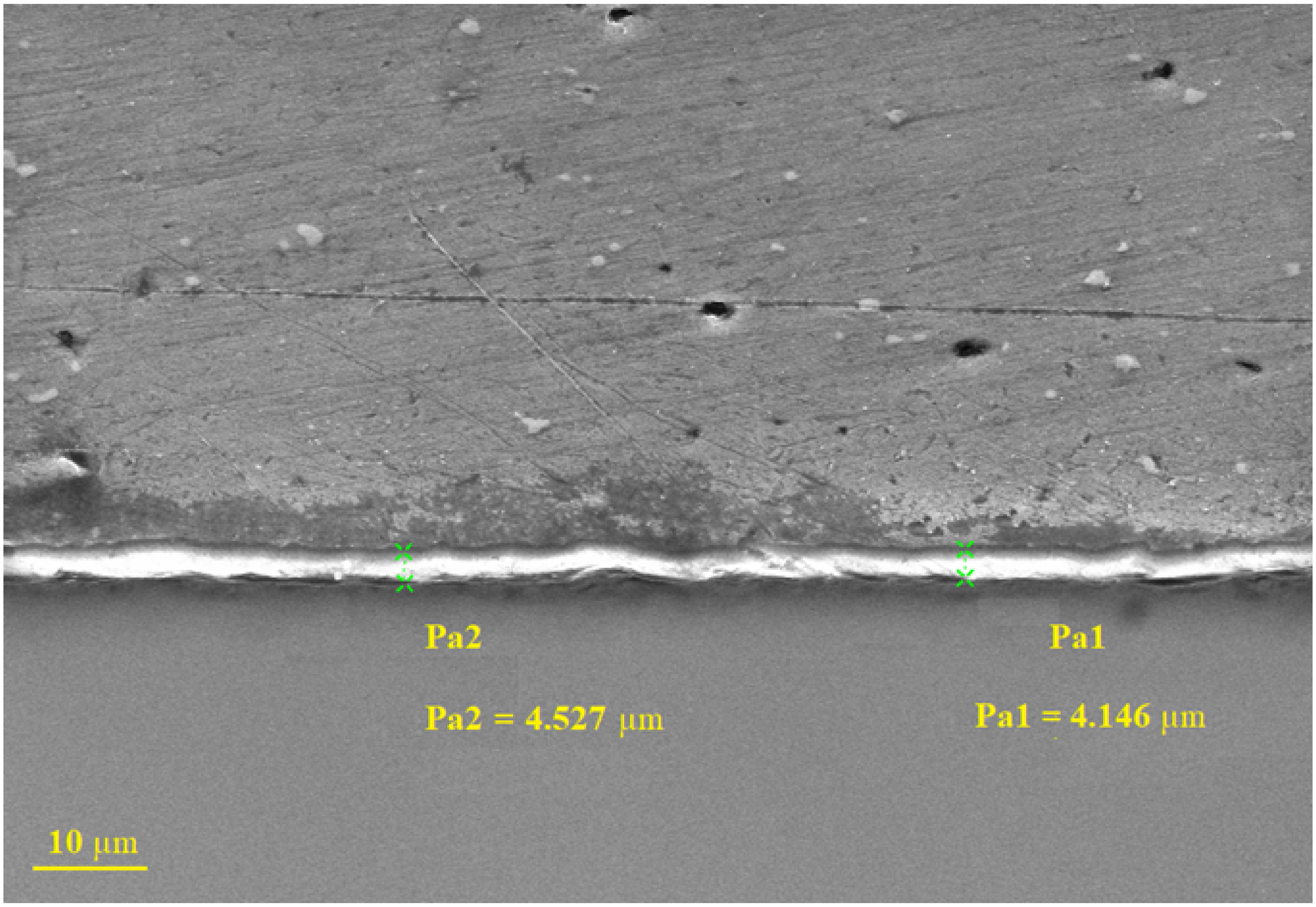

Figure 5

SEM Cross sectional views of Tio2 Coated Steel alloys

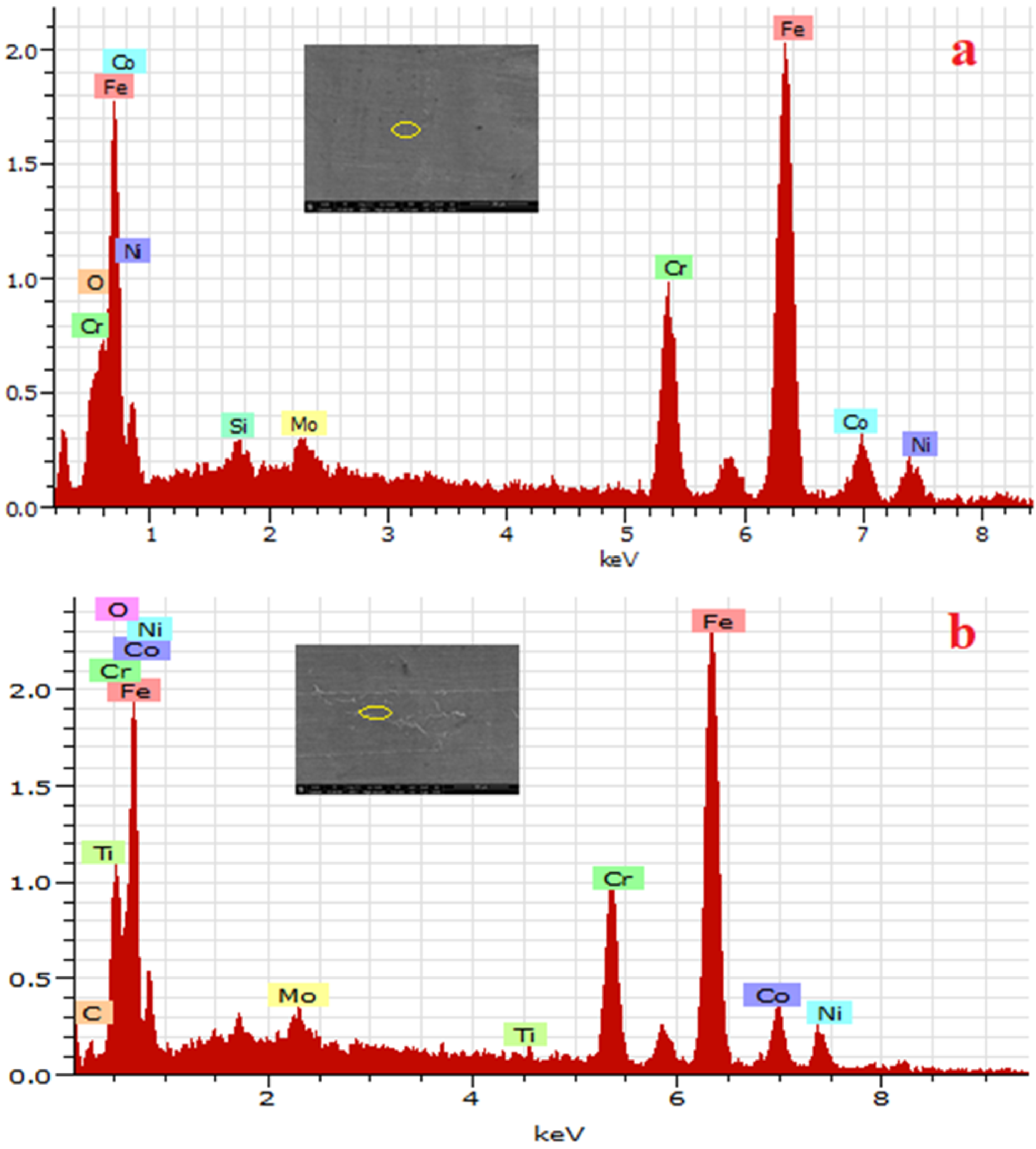

Figure 6

EDX images of (a) Bare and (b) Tio2 Spray coated Steel alloys

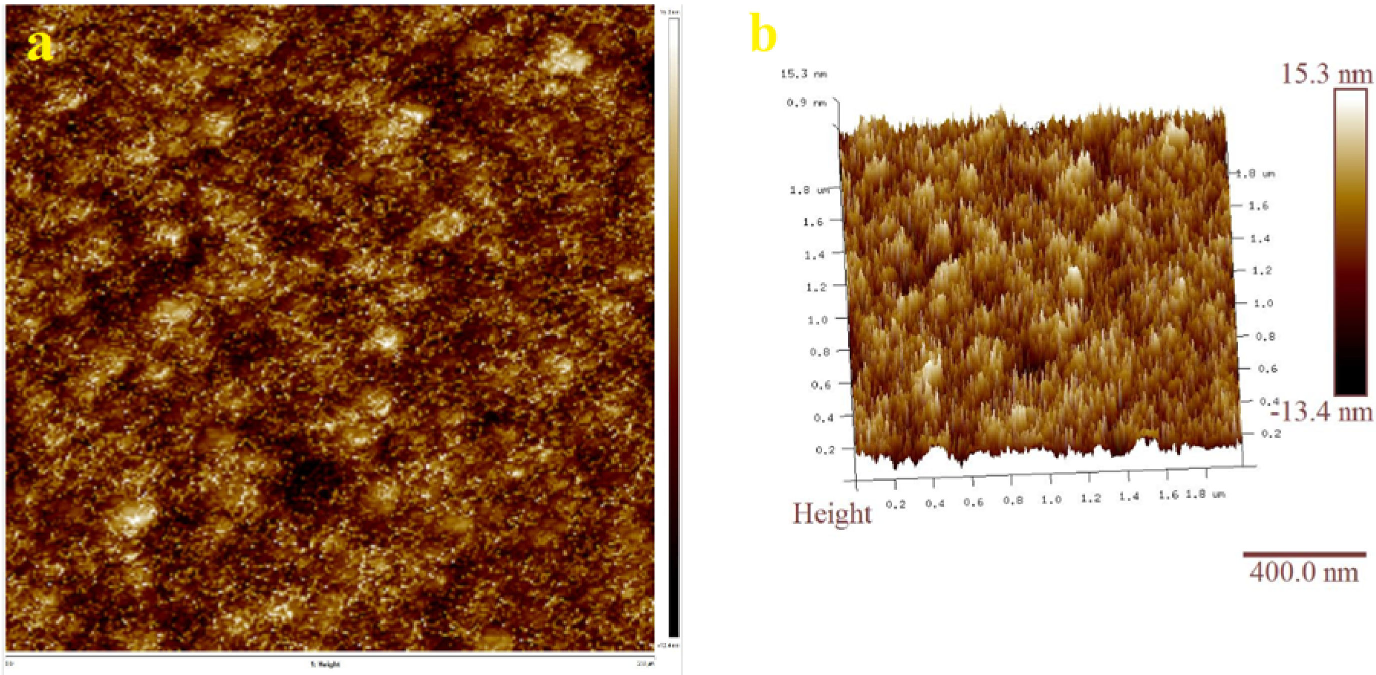

Figure 7

AFM images of Tio2 coated Steel alloy (a) 2D and (b) 3D sintered at 120 °C

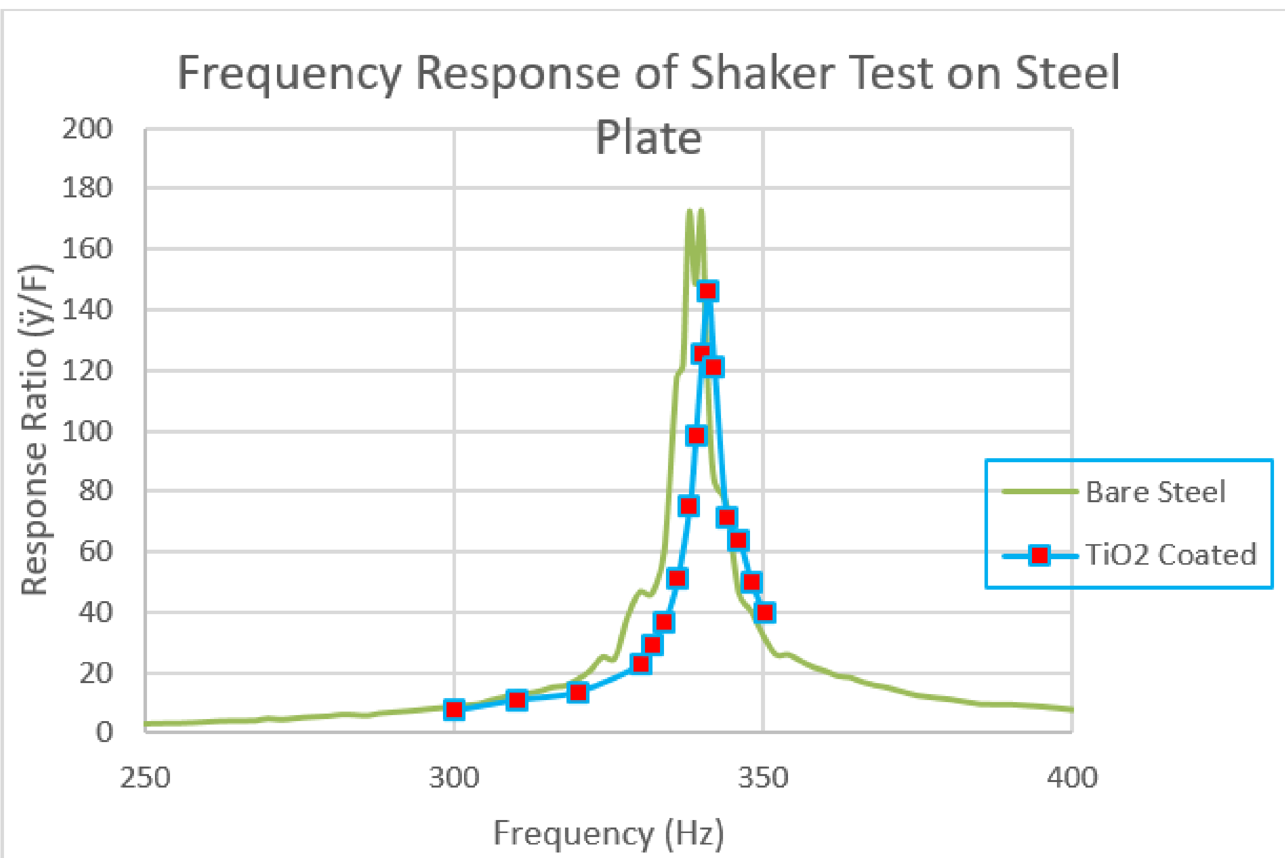

Figure 8

Shaker Test Frequency Response Function for bare, Tio2 coated steel alloys

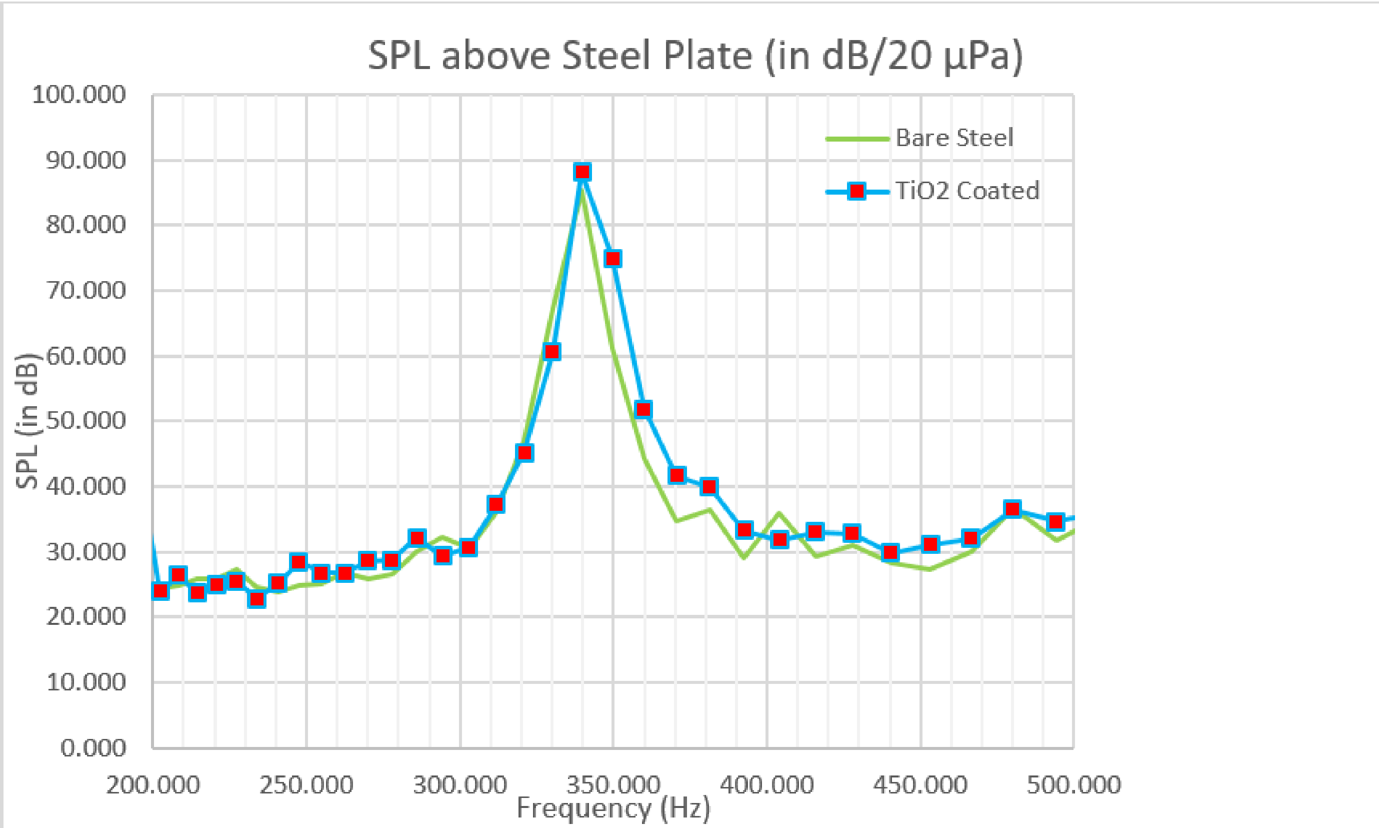

Figure 9

The comparision of Sound Pressure Level at different peaks (mode) for bare Tio2 coated Steel alloys is shown by CPB graphs