MANBODH KUMAR DAS
SAURABH DEWANGAN
HEMANT KUMAR
SOMNATH CHATTOPADHYAYA
SHIBAYAN SARKAR
and
B. S. CHOUDHARY

Wear analysis of cable shovel tooth

Cable shovel teeth are widely used for digging the fragmented rock in surface mining, which are attached in the front of shovel dipper. Shovel teeth are made up of ferro-alloy steel which has high portion of iron and rest of other elements such as, carbon silicon, aluminum, tungsten etc. The wear is described as the teeth material due to regular operation. This tool wear rate is analysed by SEM i.e. scanning electron microscopy. The aim of this study is to observe tool deterioration mechanism and chemical composition of the material. Through the EDX image, it is found that the material is made up of ferro-alloy steel and through SEM images, wearing pattern is also found. SEM is a type of electron microscope which produces three dimensional images and by the EDX image the material composition of a selected point or area is foud out. In this paper plastic deformation, cracking and cracking have been investigated. Also, wear analysis and chemical composition through SEM and EDX images have been applied to study the deformation of the tool material.

Keywords: *Shovel tooth; wear; SEM; EDX*

I. Introduction

The cable shovel is widely used for digging and loading the fragmented rock in surface mining. The shovel is operated by high voltage electric power and thus, it also is called power shovel or electric shovel. It has a front attachment, which is called dipper or bucket, which have numbers of teeth for digging the materials. Each tooth is made up of hardened steel body having high hardness, strength and wear resistance property.

Many researchers have studied the wear analysis of the worn-out tools. By using of four worn out conical from mining Dewangan et al. [1] have investigated the critical assessment of wear mechanism through SEM (scanning electron microscope) and EDX (energy dispersive X-ray) analysis. They identified the four factors by SEM analysis i.e. coal/rock intermixing, plastic deformation, rock channel formation and crushing and cracking. Also, they found the chemical composition of the worn out tool. Beste and Jacobson [3] presented a new view on the deterioration and wear of WC/Co cemented carbide rock drill buttons and found five classes of deterioration mechanism and five classes of material removal mechanisms.

The microstructure (i.e. EDX), mechanical and magnetic properties of the (W,Ti)C cemented carbides are investigated by Daoush et al [4] and by using different binder content of Co and Ni, they investigated the microstructure of each phase based on measurements of physical properties. J. Pirso et al [5] have studied about friction and wear of WC/Co cemented carbides and they found out a small amount of wear particles through SEM. The double cemented (DC) carbide which contains WC/Co in a matrix of cobalt is used and compared show DC carbide is greater resistance and fracture toughness than the conventional cemented carbide (Deng et al) [6]. They have also, investigated the microstructural effects on hybrid metal. WC based cemented carbides having to improve hardness and wear resistance (Mukhopadhyay and Basu) [7]. Based on mathematical model by applying Archard's law, Argatov et al [8] calculated the linear wear between the wires. According to the Vergne et al [9] in the hot working roll process, the wear and friction behaviour played an important role in the appearance of oxide, which is not well known. So, that they are investigated the evolution of the friction coefficient and the wear. They are also, used SEM and EDS analysis for the characterization of surface to wear analysis. On using SEM, EDS and AES (Auger Electron Spectroscopy), S. Olovsjo et al [10] analyzed wear of cemented carbide which is controlled by plastic deformation, cracking and crushing of individual WC grains.

In this paper authors tried to find out the tool deterioration mechanism and chemical composition of the cable shovel tooth through the EDX and SEM images.

II. Experiment work of of shovel tooth

A worn out shovel tooth was collected from the Dhansar OCP coal mine for wear analysis of the tool (Fig.1). Shovel teeth

Messrs. Manbodh Kumar Das, Hemant Kumar, Somnath Chattopadhyaya and Shibayan Sarkar, Dept. of Mechanical Engineering, B. S. Choudhary, Department of Mining Engineering, Indian School of Mines, Dhanbad 826 004, India and Saurabh Dewangan, Dept. of Mechanical Engg., Graphic Era University, Dehradun 248 002. Email: manbodh2k6@gmail.com, hemant08m17@gmail.com, somuismu@gmail.com, shibayan.sarkar@gmail.com, bhanwar_ism@hotmail.com, saurabh22490@gmail.com

are used for overburden digging rock/coal during surface mining process. In Fig.2, working process of shovel teeth on the surface mine is shown.

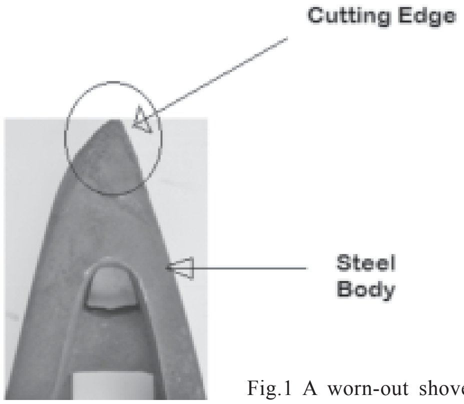

Fig.1 A worn-out shovel tooth

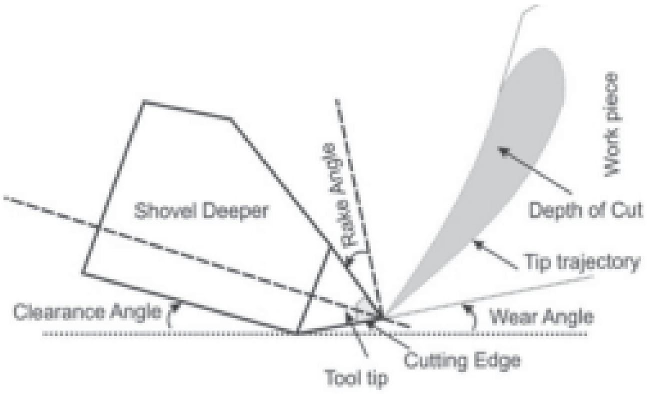

Fig.2 Working process of shovel teeth on the surface mine

To prepare the sample out of the worn out shovel teeth, initially it was cut by gas cutter, then small pieces of sample were made through wire EDM. Total six numbers of pieces were made, out of these three pieces are of 6mm and another three of 3mm thickness. Further, all pieces are analyzed through SEM and some of the pieces were used for EDX spectrograph analysis for predicting composition of rock materials.

The wear analysis of a tool on fatigue basis can be expressed as follows, Dewangan et. al [1]

$$y = 2.6\left(N_g T / Q_f n_p^3 T_0\right) \exp\left[\left(E_a / k_b\right)\left(\frac{1}{T_0} - \frac{2}{T}\right) - \sigma_{wc}^2 / \sigma_c^2\right] \quad \text{... ... (1)}$$

where, y is the average thickness of worn out layers, E_a and k_b are the average number of the particles per unit of contact area and the Boltzmann constant respectively, σ_{wc} and σ_c are the stress of WC particles and surface contact respectively, T and T_0 are the temperature of contact area and room temperature respectively, N_g is the number of hard grains of the rock per unit length and Q_f is the contact area.

The wear dependent penetration stiffness penetration stiffness $k(\delta)$ is provided by Chiaia et al. [2]:

$$k(\delta) = k_0 + C_1 A_{w,max}\left(1 + \frac{C_2}{\delta}\right)^{-1/2} \quad \text{... ... (2)}$$

where, δ is function of advancement, A_w is wear flat area, $A_{w,max}$ is the maximum asymptotic value of wear flat area, C_1, C_2 are constant and k_0 is initial penetration stiffness matrix.

III. Observations

A. Investigation on the tool deterioration mechanism

The SEM images of the tool indicate the areas where tool wear occurs. From this study we find out the tool deterioration mechanism. The topography was performed by the help of scanning electron microscopy (SEM) and the microstructure of the cross-section of the shovel tooth pick was analyzed.

These analysis shows for different kinds of mechanism of tool deterioration; these are:

1. Coal/rock intermixing
2. Plastic deformation
3. Rock channel formation
4. Crushing and cracking

1. Coal/rock intermixing

During the process of excavation, there are some particles of coal or rock get into the material of the steel body and WC-Co of the shovel tooth. When the tool is strike with high impact coal or rock material for digging, a small amount of coal or rock particle has entered, which results a small hole in the tool material and this is due to the change in temperature and pressure. Thus, the coal/rock interruption in between the WC-Co structures is a wear mechanism of this equipment as shown in Fig.3 which is indicated by white circle. The area indicated by circle is looking like a smoky structure which shows coal/rock particles lodged between WC grains which led to further degradation of binder content.

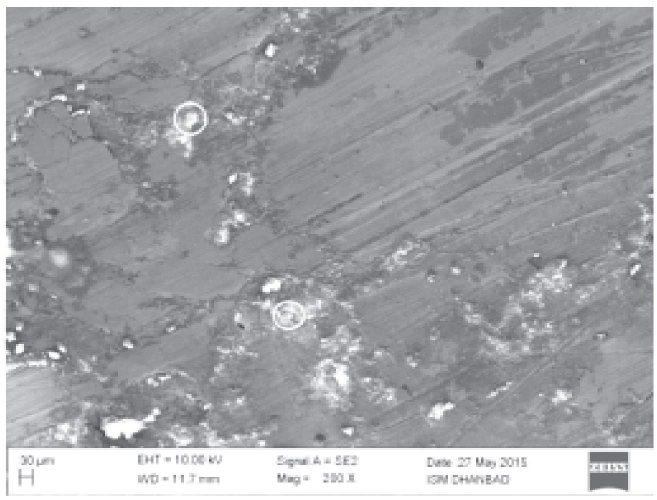

Fig.3 Coal/rock intermixing into the WC structure

2. Plastic deformation

When the tool is strike during the excavation process which makes the tool is softer because of its high friction and high temperature. After that the presence of hard rock which exist between coal mass lead to abrasion of tool and again plastic deformation takes place. These deformations can be easily recognized. The deformation is in the form of a passage which has identifiable length and breadth. These are produced by sharp rocks.

Fig.4 shows the plastic deformation area which is indicated by the circle. As a result of low applied loads, the plastic deformation is favoured when the abrasive is blunt during the contact.

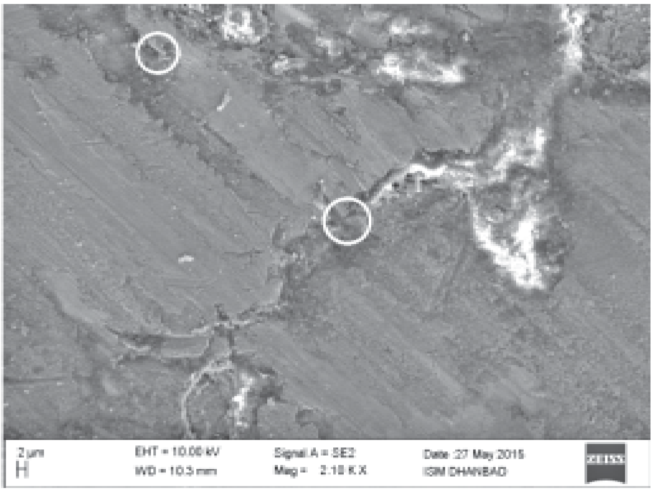

Fig.4 Plastic deformation of the tool body

3. Rock channel formation

There always exists some possibilities that rock material goes into the shovel tooth by generating a channel. The structure of channel may be in the form of straight or dendrite like. The channel width depends on the condition of passing rocks. The plastic deformation of shovel tooth causes channel formation which provides rock an easy path to go through tool. Fig.5 shows rock channel formation of the tool material which is indicated by the arrow and this channel is formed only because of the plastic deformation of the tool material.

4. Crushing and cracking

When shovel tool moves over hard rock it may lead to generation of cracks. This process imposes high force on tool. Cracks may also produce due to sudden shocks. Continuous impact on the same cracks removes that particular part of shovel tool which is crushing or in other word crushing is separation of cracked part which makes original place empty as shown in Fig.6 with circle.

The cracking of the WC grains was observed which have lowest magnification of 215× as shown in following Fig.7. The figure indicates the cracking that means wear is found and it will be breakdown of the tool material.

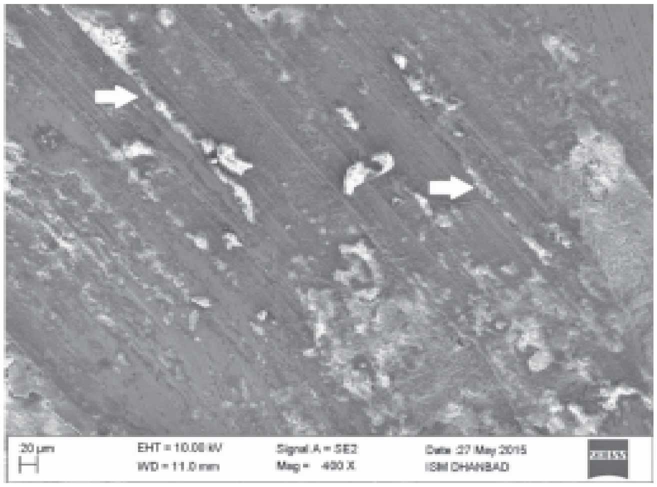

Fig.5 Rock channel formation of the tool material

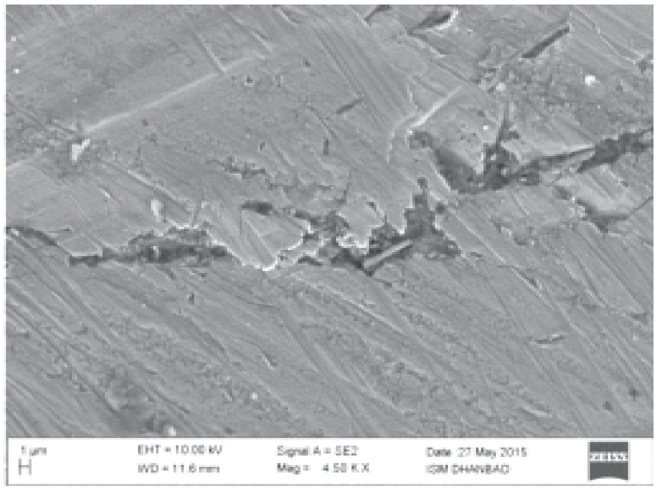

Fig.6 Crushing of the tool body

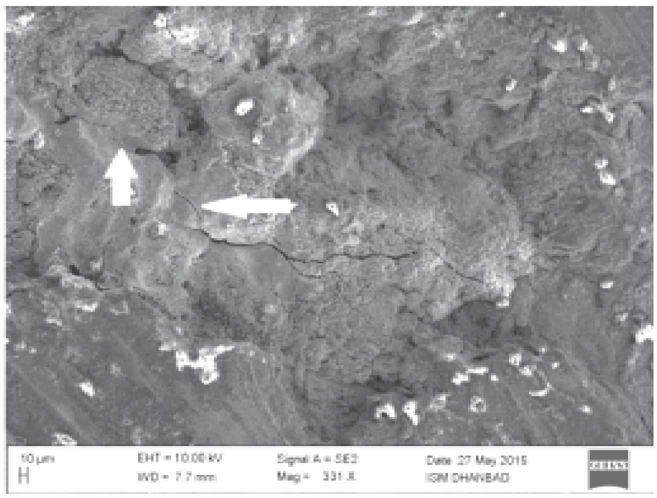

Fig.7 Cracking of the WC grain

B. Chemical analysis of the tool material

Different element contents of selected tool portion (i.e. spectrum 1 of Fig.8) are shown in EDX image (Fig.9). The

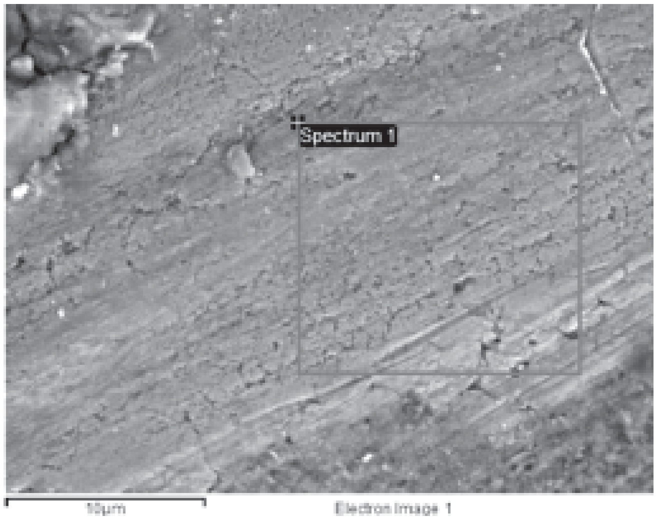

Fig.8 EDX for the worn out tool point

TABLE I: DIFFERENT ELEMENT CONTENTS OF SELECTED TOOL PORTION IN EDX IMAGE

Element	Weight %	Atomic %
C K	3.39	10.77
O K	13.02	31.06
Al K	0.76	1.07
Si K	0.54	0.74
Mn L	11.77	8.18
Fe L	70.52	48.18
Total	100.00	

same result is depicted in Table 1. The EDX analysis has been performed considering following specifications: Spectrum processing: Peak possibly omitted: 2.310 keV, processing option: All elements analyzed (normalized), number of iterations is 3.

The EDX analysis reveals that the oxygen content in the used cutting pick reaches up to 13.02 % by weight. It means there must be some rust (oxide) formation occurs. The carbon content in the metal matrix is 3.39 % by weight but in real practice the carbon content in the cutting tool should not be greater than 1.5% which means there must be some embedded carbon particles are present in the metal matrix. The percentage of manganese was found to be 11.77% by weight which represents a typical cutting tool material. Aluminum and silicon are the trace material and rest is iron.

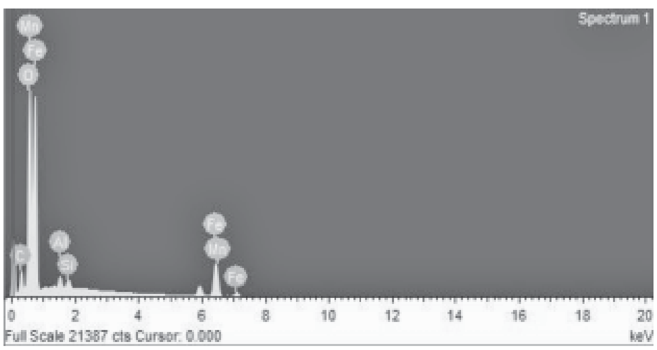

Fig.9 Variation in material composition

IV. Conclusions

In this present study wear analysis of cable shovel tooth is done using SEM and EDX analysis. From SEM analysis different wear factors like coal/rock intermixing, plastic deformation, rock channel formation and crushing-cracking are obtained. These factors are also called mechanism of tool deterioration that is primary responsible for breakdown due to cracking and crushing of the tools. Due to gradual attack between the shovel teeth and work piece i.e. coal/rock, heat is generated by friction. This phenomenon leads to plastic deformation and further it forms a rock channel in the tool material.

Material composition of the different samples of the worn out shovel tooth have been obtained from EDX analysis. The EDX analysis reveals that the oxygen content in the used cutting pick reaches up to 13.02% by weight which is much higher than the average composition of the parent base metal. It means there must be some rust (oxide) formation occurs, that will reduce the efficiency of the tool tip. The carbon content in the metal matrix is 3.39% by weight. But in real practice the carbon content in the cutting tool should not be greater than 1.5% which means there must be some embedded carbon particles are present in the metal matrix that make the material brittle in nature.

Acknowledgment

Authors would like to acknowledge the authority of Dhansar OCP for providing worn-out cable shovel tooth to carry out the study.

References

1. Dewangan, S., Chattopadhayaya, S. and Hloch, S. (2014): Wear assessment of conical pick used in coal cutting operation, Rock mech. and rock engg. Springer, 2014.
2. Chiaia, B., Brunetto, M. B. and Carpinteri, A. (2013): "Mathematical modeling of the mechanics of core drilling in geomaterials," *Machining Sci. and Tech.: An Int. J.*, Vol. 17, Issues 1, 2013, pp. 1-25.
3. Beste, U. and Jacobson, S. (2008): "A new view of the deterioration and wear of WC/Co cemented carbide rock drill buttons," *Wear*, Vol. 264, Issues 11-12, 10 May 2008, pp. 9-1141.
4. Daoush, W. M., Lee, K. H., Park H. S. and Hong, S. H. (2009): "Effect of liquid phase composition on the microstructure and properties of (W,Ti)C Cemented carbide cutting tools," *Int. J. Ref. Met. and Hard Mat.*, Vol. 27, Issue 1, January 2009, pp. 83-89.

(Continued on page 229)

X. P. (2009): "Structure, mechanical properties and friction behavior of UHMWPE/HDPE/carbon nanofibers," *Material Chemistry and Physics*, vol. 115, pp. 404-412, 2009.

10. Dommarco, R. C., Bastias, P. C., Rubin, C. A. and Hahn, G. T. (2006): "The Influence of Material Build up Around Artificial Defects on Rolling Contact Fatigue Life and Failure Mechanism," *Wear*, Vol. 260, No.11, pp. 1317-1323, 2006.
11. Tarasov, S., Kolubaev, A., Belyaev, S., Lerner, M. and Tepper, F. (2002): "Study of Friction Reduction by Nanocopper Additives to Motor Oil," *Wear*, Vol. 252, No. 1, pp. 63-69, 2002.
12. Lundgren, T. S. (1972): "Slow flow through stationary random beds and suspensions of spheres," *J Fluid Mech.*, Vol. 51, pp. 273-299, 1972.
13. Wang, B. X., Zhou, L. P. and Peng, X. F. (2003): "A fractal model for predicting the effective thermal conductivity of liquid with suspension of nano-particles," *Int. Journal on Heat and Mass Transfer*, Vol. 46, pp. 2665-2672, 2003.
14. Krieger, I. M. and Dougherty, T. J.: "A mechanism for Non-Newtonian flow in suspension of rigid spheres," *Trans. Soc. Rheology*, Vol. 3, pp. 137.

WEAR ANALYSIS OF CABLE SHOVEL TOOTH

(Continued from page 221)

5. Pirso, J., Letunovits, S. and Viljus, M. (2004): "Friction and wear behavior of cemented carbides," *Wear*, Vol. 257, Issues 3-4, Aug., pp. 257-265.
6. Deng, X., Patterson, B. R., Chawla, K. K., Koopman, M.C., Fang, Z., Lockwood, G. and Griffo, A. (2001): "Mechanical properties of a hybrid cemented carbide composite." *Int. J. Ref. Met. and Hard Mat.*, Vol. 19, Issues 4-5, July-Nov. 2001, pp. 547-552.
7. Mukhopadhyay, A. and Basu, B. (2011): "Recent developments on WC-based bulk composites," *J. of Mat. Sci.*, Vol. 46, Issue 3, Feb. 2011, pp. 571-589.
8. Argatov, I. I., Gomez, X., Tato, W. and Urchegui, M.A. (2011): "Wear evolution in a stranded rope under cyclic bending: Implications to fatigue life estimation," *Wear*, Vol. 271, Issues 11-12, 2 Sept. 2011, pp. 2857- 2867.
9. Vergne, C., Boher, C., Levaillant, C. and Gras, R. (2001): "Analysis of the friction and wear behavior of hot work tool scale: application to the hot rolling process," *Wear*, Vol. 250, Issues 1-12, 2001, pp. 322-333.
10. Olovsjo, S., Johanson, R., Falsafi, F., Bexell, U. and Olsson, M. (2013): "Surface failure and wear of cemented carbide rock drill buttons-the importance of sample preparation and optimized microscopy settings," *Wear*, Vol. 302, Issues 1-2, April-May 2013, pp. 1546-155.

EROSION ANALYSIS OF COAL MINE PIPELINE VALVES AT DIFFERENT OPENING CONDITIONS

(Continued from page 225)

6. Bitter, J. G. A. (1963): "A study of erosion phenomena: Part II." *Wear* (1963), 6(3): pp. 169-190.
7. Neilson, J. and Gilchrist, A. (1968): "Erosion by a stream of solid particles," *Wear* 11, pp. 111-122.
8. Wallace, M. S., Dempster, W. M., Scanlon, T., Peters, J. and Mc Culloch (2004): "Prediction of impact erosion in valve geometries," *Wear*, 256, pp. 927-936.
9. Hashish, M. (1987): Modified model for erosion, Seventh International Conference on Erosion by Liquid and Solid Impact, Cambridge, England, pp. 461-480.
10. Hutchings, I., Winter, R. and Field, J. (1976): Solid particle erosion of metals: the removal of surface material by spherical projectiles, Proc. R. Soc. Lond. Ser. A Math. Phys. Sci. 348, pp. 370-392.
11. ANSYS FLUENT (2009): ANSYS FLUENT Theory Guide ANSYS Inc., Southpointe, 275 Technology Drive, Canonsburg, PA.