

Importance of Quality Control of Wear Resistant Overlays in Oil Sands Production Operations

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ABSTRACT

Equipment and piping in Oil Sands operations are subject to erosion, abrasion and impact wear while handling dry ore and wet slurry. Wear resistant overlays play a very important role in extending the service life of various equipment and piping in Oil Sands production operations. Tungsten carbide overlays and chromium carbide overlays are widely used to increase the wear resistance of equipment and piping. Bonding with the base material, overlay chemistry, carbide distribution, carbide volume fraction, dilution, and through thickness hardness are all important factors in determining the wear resistance and service life of overlays. Qualification and production testing are necessary to ensure the quality of the overlays. Service life of overlays depend on the quality control process adopted during the fabrication process.

Wear resistant overlays have been in use for a very long time. Lots of work has been done in the last 10 years to increase the service life of overlays and minimize unexpected premature failures. A significant part of this work was focused on quality control and testing requirements of the overlays. This resulted in new testing methodologies and improved inspection requirements.

Key words: Tungsten Carbide Overlay (WCO), Chromium Carbide Overlay (CCO), Oil Sand, Wear, Loss of Primary Containment (LOPC), Canadian Natural Resources Limited (Canadian Natural)

INTRODUCTION

Canadian Oil Sands mining operations have been producing oil from sand ore from the early 1960s. Oil Sands mainly consists of high hardness quartz, silica, bitumen and water. Bitumen production processes include mining the sand, washing it with hot water, slurry transportation, tailing disposal and bitumen production. Abrasion, gouging wear, impact wear, erosion and erosion-corrosion are predominant degradation mechanisms in Oil Sand mining operations. Dry and wet operations dealing with Oil Sands, cause significant wear and corrosion issues on carbon steel materials. Carbon steel is widely used for the equipment, piping, and pipelines due to relatively low cost, ease of fabrication and availability. However, carbon steel has marginal wear, erosion, corrosion resistance, and a relatively short service life. Oil Sands production operators are continuously looking for wear resistant materials. High alloy steels, cast white irons, wear resistant overlays, and non-metallic lining materials are widely used in fabrication of various equipment to improve erosion and corrosion resistance properties. Chromium Carbide Overlays (CCO), and Tungsten Carbide Overlays (WCO) are two typical wear resistant overlay materials widely used in Oil Sand production operations. High hardness, proper chemical composition, metallurgical bond between carbon steel and overlay are required for WCO and CCO to resist severe wear, erosion, and/or corrosion. However, the industry had seen a number of premature failures on overlaid equipment and piping due to inferior quality of the overlays. Typical deficiencies of CCO and WCO overlays include low hardness, spallation, insufficient carbide volume fraction, carbide segregation, base metal dilution, and low through-thickness hardness, etc. These deficiencies resulted in pre-mature failures of the overlays, loss of primary containment (LOPC), production losses, and safety/environmental impact to the oil sand production operators. Seeing the premature failures, Oil Sand operators had worked hard to establish strict overlay standards and requirements to acquire quality overlay products. This paper describes typical wear mechanisms in Oil Sands production operations, field premature failures due to the poor overlay quality, importance of quality control and testing requirements during the fabrication, and overlay qualification. It would also summarize the recent improvements on quality control of WCO and CCO in order to increase the service life and reduce premature failures. Finally, it describes the benefits from implementing company specific overlay standards, overlay qualification & production testing, and quality control.

WEAR MECHANISMS IN OIL SAND MINING OPERATIONS

Typical wear mechanisms in Oil Sand operations include low-stress abrasion, high-stress abrasion, impact, gouging, erosion, and erosion-corrosion.

Low-Stress Abrasion, also called scratching abrasion, characterized by abradant fracture, the particles generally retain their size, shape in the process. The material thins out by micro cutting and the material with higher hardness will have higher resistance to surface indentation, abrasion or micro cutting. This wear mechanism is typical in mining, ore preparation, extraction, slurry piping, and slurry pumps.

High-Stress Abrasion, also called grinding abrasion, in contrast to the low stress abrasion, the abradant fractures into smaller, usually sharp and angular pieces. The combination with higher contact stresses leads to indentation, scratching, and micro ploughing of the material. High-stress abrasion is often experienced in Ground Engaging Tools (GET) shovels and crushers.

Impact wear refers to the continuous collision of large solids with sufficient energy onto the part surface. The part will experience material deformation, cracking, cutting, fatigue, or fracturing, etc. in mining, ore preparation, slurry piping, and slurry pumps. Gouging wear is a severe form of high-stress abrasion caused by the fractured solids into sharp and angular particles under high external compressive stress.

It will result in sizable and significant grooves or craters on the part surface. This wear mechanism also found in mining on GET shovels and in ore preparation such as crushers.

Erosion caused by repeated impact of small, solid particles results in loss of surface material called as solid particle erosion (SPE). This phenomenon is expected wherever hard particles entrained in a gas or liquid medium impinge on a solid at any significant velocity, typically greater than 1 m/s. Solid particle erosion is more significant in liquid media containing solid hard particles. This wear mechanism often exists in slurry piping and slurry pumps.

Erosion-Corrosion is a synergetic wear mechanism in aqueous process streams on equipment and piping in Oil Sands such as slurry piping, pump box, and pumps, etc. Corrosion leads to the formation of a loose scale prone to be removed by erosion, while erosion causes the removal of scale and enhances corrosion. Erosion-Corrosion can be either erosion-dominant or corrosion dominant depending on the individual equipment or piping. It generally has a much higher wear rate than each individual mechanism.

BRIEF INTRODUCTION OF CCO AND WCO

Oil Sand operators are continuously trying to improve service life of the equipment, piping and pipelines in bitumen production operations. Wear resistance overlays play a very important role in increasing the service life. Chromium Carbide Overlay (CCO) and Tungsten Carbide Overlay (WCO) are widely used in Oil Sands mining operations for this reason. Base carbon steel or stainless steel materials take care of primary containment, while high-hardness overlays help to reduce wear rate and increase the service life.

CCO is applied on the surface of carbon steel or stainless steel by semi-automatic as well as manual welding processes. The chemistry of the overlay consists of minimum 25% Cr, minimum 3%C, 1-3%Mn and 0-1% Mo. This overlay chemistry results in formation of MC (M=Cr, Fe and Mn) carbides. The wear resistance property of CCO comes from formation of M_7C_3 primary carbides. The hardness of primary chromium carbides is greater than 1500Hv. CCO overlays typically have stress relief cracks. These cracks are generally acceptable if they do not extend to the base materials. However, the presence of under-bead cracks may result in spallation.

WCO is a composite overlay normally with 60-70wt% of hard tungsten carbides (1600-3000 HV) dispersed in soft or hard Ni based flux alloy matrix (NiSiB or NiCrSiB with 30-60 HRC). WCO combines the high hardness of tungsten carbides and the toughness of a Ni-based matrix. WCO is the wear resistant material option of choice after other common wear materials like CCO, high chrome white iron, and elastomers, etc. are exhausted. Common WCOs in Oil Sands are generally produced using Plasma Transfer Arc Welding (PTAW), Gas Metal Arc Welding (GMAW), Laser Cladding and Spray & Fuse, or Hot Isostatic Pressing (HIP). The overlay thickness ranges from 0.7 to 40 mm in practice depending on the individual overlay method used.

The main difference between CCO and WCO is that the carbides in CCO are formed during the welding process while the carbides in WCO are pre-mixed in the powder feed or wire/electrode.

Ease of fabrication, inspection and possibility of field repairs make these overlays widely used as wear overlay materials.

TYPICAL DEFICIENCIES IN CCO AND WCO OVERLAYS

There are some common overlay deficiencies for both CCO and WCO, such as poor bonding either due to lack of fusion or under-bead cracking, low hardness, insufficient carbide fraction, carbide decomposition, porosity, insufficient overlay thickness, insufficient bead overlap, etc. For CCO, base metal dilution would be a special deficiency. WCO experiences carbide settling. If one or more deficiencies exist in CCO or WCO, the overlay parts may experience fast wear or premature failure.

Lower carbide volume fraction or non-uniform carbide distribution results in variations in through thickness hardness. Improper chemistry of the overlay results in reduced carbide volume fraction and corrosion resistance. Two main factors that influence spallation are underbead cracking and higher hardness. Underbead cracking is not completely avoidable in overlays but excessive underbead cracking results in spallation of the overlay. Higher heat input results in increased base metal dilution and lower heat input increases the tendency towards underbead cracking. Repeated impact loading of a high hardness overlay causes microcracking and microfracturing resulting in spallation.

1. TUNGSTEN CARBIDE OVERLAY (WCO) IN OIL SANDS

Table 1. Summarizes the typical applications of various WCOs in Canadian Natural Oil Sands operations. Predominantly WCO overlaid equipment is used in dry ore processes like mining and ore preparation with severe abrasion, gouging, and impact wear. Froth Treatment plants have also adopted WCOs for equipment and piping experiencing high-speed jet, steam cavitation, or high turbulence erosive wear.

Table 1. Typical applications of various WCOs at Canadian Natural Oil Sands sites

Plant Section	Applications	Wear Mechanisms
Mining	GET Shovel Teeth: PTAW WCO	Low/high Stress Abrasion, Impact, Gouging
Ore preparation	Double roll crusher teeth and crusher segments: PTAW WCO	Low/high Stress Abrasion, Impact, Gouging
	Vibrating screen panels and rotary breaker screen liners: PTAW WCO	Low stress abrasion, Impact
Extraction	Slurry pumps (suction liners and impellers): Laser Cladding WCO	Low Stress Abrasion, Erosion, Erosion/Corrosion, Impact
Tailing	Slurry pumps (suction liners and impellers): Laser Cladding WCO	Low Stress Abrasion, Erosion, Erosion and Corrosion, Impact
Froth Treatment	Direct steam injection slurry heater, slurry heater seats and plugs, high wear spool, and ball valves: ConformaClad™ WCO or PTAW WCO	High Speed Jet Erosion, Steam Cavitation
	Slurry heater static mixer: ConformaClad™ WCO or PTAW WCO	High Speed Jet Erosion, Steam Cavitation
	High wear spools and nozzles: PTAW WCO or Spray & Fuse WCO	High Speed Jet Erosion, Steam Cavitation
	Slurry pumps (suction liners and impellers): Laser Cladding WCO	Erosion, Erosion and Corrosion
	Slurry pumps (suction and discharging spools): Spray & Fuse WCO	Erosion, Erosion and Corrosion

WCO is an excellent wear-resistant material when it is properly applied. However, if the overlay vendor does not pay attention to quality control, the parts with WCO could fail quickly due to the internal defects in the overlay. Such defects include poor bonding, insufficient overlay overlap, insufficient overlay thickness, low carbide content, carbide settling, and carbide decomposition etc. The sections below provides some typical examples or case studies of premature failures of WCO parts owing to the poor overlay quality.

1.1 Poor Bonding

Poor bonding due to lack of fusion or under-bead cracking was a common reason contributing to the premature failure of WCO parts at Canadian Natural Oil Sands sites. Under high impact or impingement or high external stress, WCO with poor bonding will either spall off or delaminate from the base material.

1.1.1 Mining shovel latch keeper inserts

Laser Cladded WCO on a mining shovel latch keeper insert had been found to have either spalled off from the base material or delaminated between pass layers during service. Figure 1 (a) showed the WCO had been delaminated between two pass layers, indicating the lack of fusion between the two passes during the cladding process. The cross-sectional picture in Figure 1 (b) suggested that there were many defects like cracking, pores, and poor bonding. The very flat WCO/base interface and minimal heat-affected zone (HAZ) were the sign of lack of fusion. Insufficient heat input could be the possible reason for lack of fusion of WCO either between passes or to the base material.

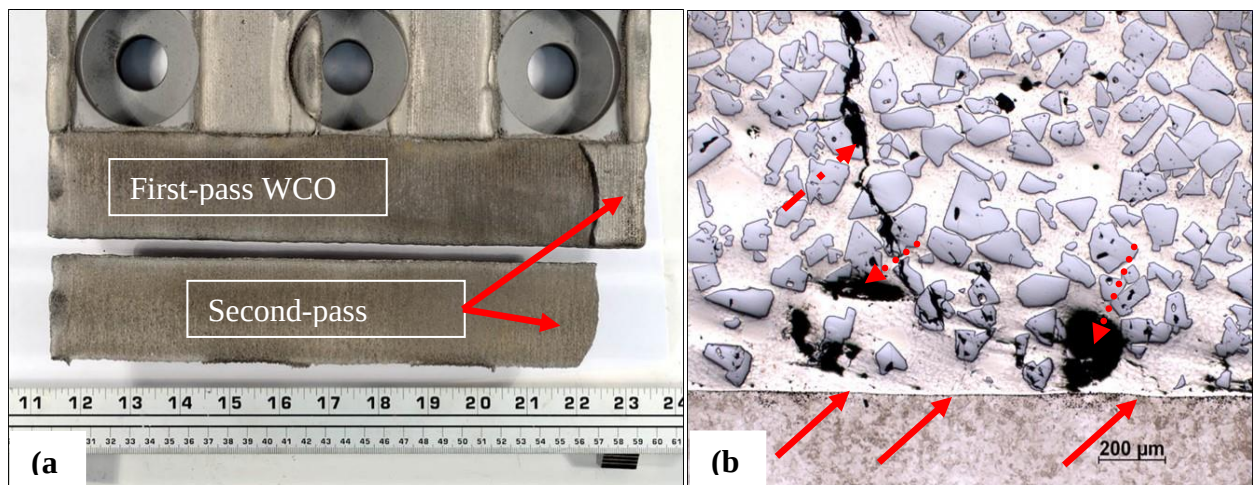


Figure 1. Premature failure of mining shovel latch insert with two-pass Laser Cladding WCO. (a) Delamination of WCO between WCO passes; (b) Cross-sectional picture showing cracking, porosity, and minimal bond between WCO and steel base.

1.1.2 Double-roll crusher teeth

Canadian Natural Oil Sands sites use double roll crushers to break the oil sand ore for downstream processes. The crusher teeth are carbon steel cones lined with two-pass PTAW WCO (6mm) on the high wear area as shown in Figure 2. These teeth would see severe low/high stress abrasion, impact, and gouging wear. The tooth performance is largely dependent on the batch quality of PTAW WCO.



Figure 2. PTAW WCO/carbon steel double-roll crusher teeth.

The site had experienced many early failures of PTAW WCO crusher teeth due to the quality of WCO, especially attributed to poor bonding. Figure 3 shows typical prematurely worn out PTAW WCO on crusher teeth. The cone tooth wore out and exposed the teeth holder on the crusher segment. Wear damage was seen on the external surface of tooth holder in Figure 3 (a). By examining the remained WCO on the crusher teeth, local overlay spallation was observed in Figure 3 (b). The WCO lined tooth was sectioned to examine the cross section for more details. As shown in Figure 4 (a) and (b), the WCO had a lot of through thickness transverse cracks and horizontal cracks. Significant under-bead cracks were present at the WCO/CS interface. All the lab results suggested that excessive cracks and under-bead cracking had resulted in the spallation of WCO under high impact and abrasion, and subsequent loss of protection of the carbon steel base. The quality issue of WCO had made the crusher teeth among the top maintenance bad actors with an annual part cost of ~\$1.3M CAD.