Maintaining the Gold Standard in Platinum Jewellery Application of Process Mineralogy to Quality Control in Platinum Manufacturing

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Abstract

Process mineralogy has traditionally been applied to ore characterisation, mineral beneficiation, and metallurgical process optimisation. The same analytical methodologies, however, can provide valuable insights into downstream manufactured products where material purity and quality are critical. Platinum jewellery production requires exceptionally high metal purity, with even trace contamination capable of affecting appearance, durability, castability, and customer acceptance.

This study demonstrates the application of automated scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and process mineralogical analysis to investigate impurity phases within platinum-ruthenium jewellery alloys. Multiple production samples were examined to quantify the abundance, composition, and distribution of non-metallic inclusions. Carbon-rich phases represented the dominant impurity population, while significant calcium-, silicon-, oxygen-, and aluminium-bearing inclusions were also identified. The repeat sample analysis demonstrated reduced impurity levels compared with earlier investigations, indicating that SEM-based monitoring can provide quantitative evidence of process improvement.

Keywords: Process mineralogy; platinum jewellery; SEM-EDS; flux contamination; slag contamination; platinum-ruthenium alloy; quality control

1. Introduction

Process mineralogy has become an integral component of modern mineral processing by linking mineralogical characteristics with metallurgical performance. Applications traditionally focus on ore characterisation, liberation analysis, recovery optimisation, and plant troubleshooting (Petruk, 2000; Fandrich et al., 2007), however, its application to downstream manufactured products remains relatively limited. Platinum jewellery manufacturing represents a unique environment where the consequences of contamination can be disproportionately high. Even trace levels of impurities and inclusions can adversely affect casting quality, microstructural uniformity, surface finish, wear performance, and the overall quality of platinum jewellery products (Klotz and Fryé, 2019; Miller et al., 2005).

Platinum-ruthenium alloys are among the preferred platinum jewellery alloys because they exhibit excellent corrosion resistance, good castability, attractive white colour, high hardness, and favourable mechanical properties for jewellery applications (Miller et al., 2005;

Klotz and Fryé, 2019). Maintaining alloy purity throughout the manufacturing process from melting, casting, rolling, to finishing operations is therefore critical (Figure 1). Potential contamination sources include crucibles, refractory materials, furnace linings, fluxing agents, polishing compounds, rolling equipment, and environmental particulates.

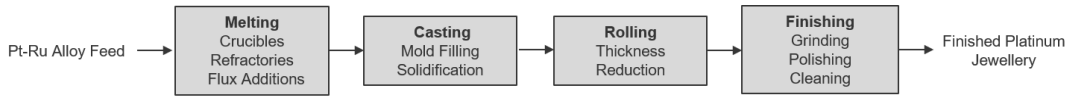


Figure 1. Simplified platinum-ruthenium jewellery manufacturing process showing major production stages and potential contamination pathways

Conventional quality-control techniques often identify that contamination exists but may be limited in their ability to determine contaminant origin. Automated SEM-based process mineralogy offers a unique opportunity to characterise impurity populations and assign likely contamination pathways based on elemental associations and phase compositions. Several ways in which this can be done include;

1. Quantifying impurity populations within platinum-ruthenium jewellery alloys.
2. Characterising the composition of impurity phases.
3. Identifying elemental signatures associated with impurity populations.
4. Evaluating the influence of process modifications on impurity abundance.
5. Demonstrating the applicability of process mineralogy as a quality-assurance and process optimisation tool in platinum jewellery manufacture.

2. Methodology

2.1 Samples

A suite of platinum-ruthenium jewellery samples was examined. The investigation included production samples, repeat samples, and reference materials analysed using automated mineralogical and SEM-based techniques. Samples were directly mounted onto existing polished blocks using carbon tape.

2.2 SEM and EDS Analysis vs Automated Analyses

Initial investigations were conducted using conventional scanning electron microscopy (SEM) coupled with energy-dispersive X-ray spectroscopy (EDS). The primary objective of this phase of the study was to identify the presence, morphology, and distribution of impurity phases within platinum-ruthenium jewellery products. Backscattered electron (BSE) imaging was used to identify regions of compositional contrast within the platinum-ruthenium alloy, while secondary electron (SE) imaging provided information on surface topography and the occurrence of physical defects. Energy-dispersive X-ray spectroscopy (EDS) was subsequently used to determine the elemental composition of individual inclusions and contamination features.

2.3 Automated Process Mineralogy

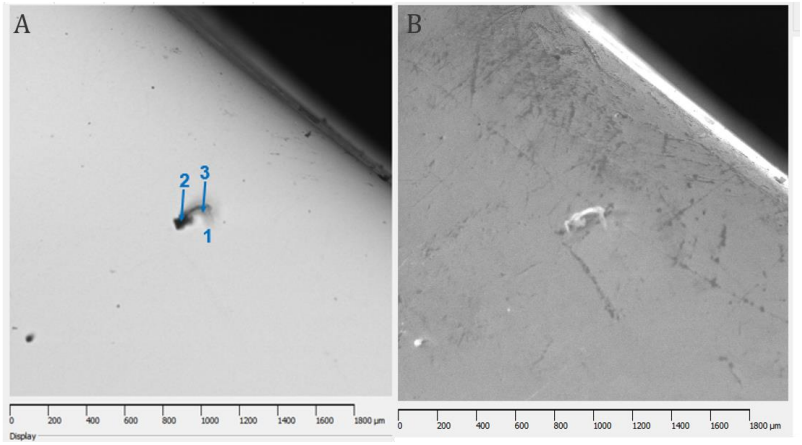
Following the initial SEM-EDS investigation, automated SEM-based process mineralogical analysis was implemented to quantitatively evaluate the effectiveness of process modifications introduced by the manufacturer. These modifications included changes to crucible materials, protective crucible coatings, and other consumables used during the melting and casting stages of production.

While conventional SEM provided detailed qualitative information regarding the nature of contamination, automated process mineralogy enabled statistically robust quantification of impurity populations across large sample areas. Automated phase identification and classification were used to measure the relative abundance and distribution of impurity phases within the platinum-ruthenium matrix.

3. Results

3.1 Manual SEM-EDS Investigation

A manual SEM investigation identified discrete inclusions within the platinum-ruthenium matrix. Figure 2 illustrates a representative impurity particle identified during the initial SEM investigation. The inclusion appears as a dark feature in the BSE image (Figure 2a), indicating a substantially lower average atomic number than the surrounding platinum-ruthenium matrix. The corresponding secondary electron (SE) image (Figure 2b) provides additional morphological and topographic information on the particle and the surrounding alloy surface. These surface characteristics were used to identify and confirm the presence of contaminant phases and to evaluate their potential effect on the sample's physical properties. EDS analyses show that the surrounding matrix (Spot 1) consists of approximately 92.13 wt.% Pt and 7.87 wt.% Ru, while analyses of the impurity feature (Spots 2 and 3) revealed elevated carbon concentrations ranging from 58.20 to 71.97 wt.% together with minor oxygen. These observations demonstrate the presence of discrete carbon-enriched inclusions within the platinum-ruthenium alloy.

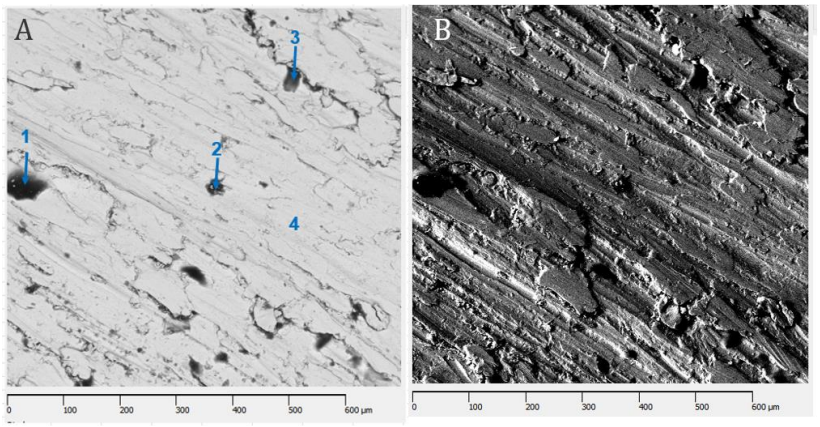


C

Normalized weight concentration				
Spectrum	C	O	Ru	Pt
Spot 1			7.87	92.13
Spot 2	71.97	6.14		21.89
Spot 3	58.20	3.16		38.64

Figure 2. Manual SEM investigation of a carbonaceous inclusion within a platinum-ruthenium jewellery alloy. (A) Backscattered electron (BSE) image showing a low atomic number inclusion appearing darker than the surrounding Pt-Ru matrix. (B) Secondary electron (SE) image highlighting the surface morphology of the impurity particle. (C) EDS spot analyses demonstrating that the surrounding matrix (Spot 1) consists of approximately 92.13 wt.% Pt and 7.87 wt.% Ru, while Spots 2 and 3 are enriched in carbon (58.20-71.97 wt.% C) with minor oxygen, indicating a predominantly carbonaceous contaminant.

In addition to discrete inclusions, impurity features associated with mechanically worked surfaces were also observed. Figure 3 presents an example of impurity particles distributed along a cut surface. The BSE image (Figure 3a) shows several dark features aligned with deformation structures within the material, while the corresponding SE image (Figure 3b) highlights the pronounced surface topography associated with rolling and subsequent cutting. EDS analyses of the impurity particles (Points 1 to 3) indicate elevated carbon concentrations ranging from approximately 42 to 66 wt.% together with oxygen and minor quantities of sodium, aluminium, silicon, chlorine, calcium, and iron. In comparison, the surrounding matrix (Point 4) contains substantially lower carbon concentrations and significantly higher platinum content. The compositional diversity observed within these particles indicates that impurity features identified are not chemically uniform and may comprise multiple contaminant populations.



C

Normalized weight concentration

Spectrum	C	O	Na	Al	Si	Cl	Ca	Fe	Pt
Point 1	66.26	7.88	0.90	0.30	0.40	1.96	0.79	1.42	20.09
Point 2	41.63	9.45	1.76	1.29	1.71	4.76	1.95	1.81	35.63
Point 3	56.94	8.49	0.75	0.34	0.70	1.68	1.14	1.14	28.82
Point 4	16.98	2.17	2.57	0.73	1.02	3.14	1.68	1.80	69.91

Figure 3. Carbon-rich surface contamination identified on a rolled platinum-ruthenium jewellery alloy. (A) Backscattered electron image showing multiple dark inclusions distributed along the deformed surface. Analysis points (1-4) indicate locations selected for EDS investigation. (B) Secondary electron image illustrating the surface topography and deformation features associated with rolling and subsequent processing. (C) EDS analyses reveal carbon-rich contaminants containing elevated oxygen, chlorine, sodium, calcium, silicon, aluminium and iron, indicating a chemically complex impurity assemblage containing carbon, oxygen, chlorine, sodium, calcium, silicon, aluminium, and iron

3.2 Automated SEM-Based Process Mineralogy

Following the manual SEM-EDS investigation (Section 3.1), the manufacturer produced platinum-ruthenium material under a series of different process conditions, on the basis of the impurities identified. Automated SEM-based process mineralogical analysis was then conducted on material for each condition to quantitatively assess impurity populations

For each condition, a representative section of rolled material was prepared and analysed using automated SEM-based mineralogical techniques. A predefined analysis area was selected to ensure consistency between samples. Representative mineralogical maps for the Control sample and Condition 1 are shown in Figure 4. The maps illustrate the spatial distribution of impurity phases identified within the rolled material. Mineral classification enabled quantification of platinum-ruthenium and the various impurity populations present within each sample. The results are summarised in Table 1.

Platinum-ruthenium was the dominant phase in all analysed samples, ranging from 99.442 wt.% to 99.930 wt.% (Table 1). The highest platinum-ruthenium abundance was recorded for Condition 3 (99.930 wt.%), followed by Condition 1 (99.910 wt.%). The Control sample contained 99.601 wt.% platinum-ruthenium, while Condition 2 recorded 99.442 wt.%.

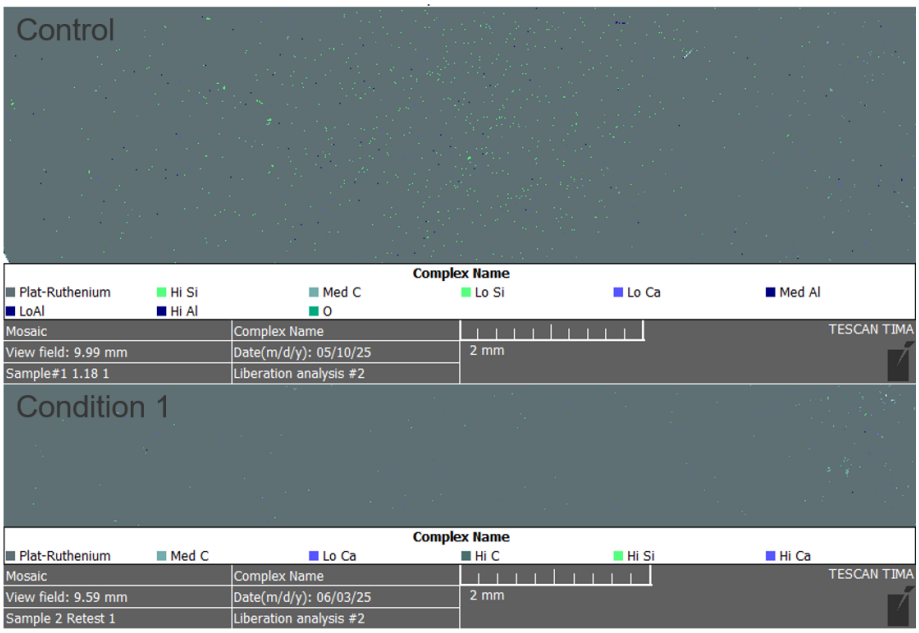


Figure 4. Representative autoSEM mineralogical maps of rolled platinum-ruthenium material from the Control sample and Condition 1. Coloured particles represent impurity populations, while the grey background corresponds to the platinum-ruthenium matrix.

Table 1. Quantitative phase abundances (wt.%) determined by autoSEM-based mineralogical analysis for the Control sample and four evaluated process conditions. Results are reported as relative abundances of platinum-ruthenium and impurity populations grouped according to their dominant elemental composition.

Phases	Control	Condition 1	Condition 2	Condition 3	Condition 4
High C (>50% C)	0.018	0.017	0.009	0.006	0.015
Med C (30-50%C)	0.020	0.059	0.100	0.042	0.278
Low C (<30% C)	0.000	0.000	0.000	0.000	0.000
High Ca (>8% Ca)*	0.000	0.000	0.003	0.000	0.003
Med Ca (4-8 % Ca)	0.000	0.000	0.004	0.000	0.004
Low Ca (<4% Ca)**	0.004	0.003	0.034	0.005	0.030
High Si (>40% Si)	0.327	0.002	0.272	0.007	0.008
Low Si (<20% Si)	0.008	0.001	0.069	0.006	0.007
High Al (>20% Al)	0.012	0.004	0.013	0.000	0.004
Med Al (5-20% Al)	0.007	0.001	0.024	0.000	0.004
Low Al (<5% Al)	0.002	0.001	0.018	0.000	0.006
O	0.001	0.004	0.012	0.002	0.023
Other	0.001	0.000	0.002	0.000	0.001
PlatRuthenium	**99.601**	**99.910**	**99.442**	**99.930**	**99.619**
Total	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**

Several impurity populations were identified and quantified across the sample set. Carbon-bearing phases were present in all analysed conditions, with high-carbon (>50% C) phases ranging from 0.006 wt.% to 0.018 wt.% and medium-carbon (30-50% C) phases ranging from 0.020 wt.% to 0.278 wt.%. Calcium-bearing phases occurred at relatively low abundances.

High-calcium (>8% Ca) phases were only identified in Conditions 2 and 4, while medium-calcium (4-8% Ca) phases were similarly restricted to these two conditions. Low-calcium (<4% Ca) phases were present in all samples and ranged from 0.003 wt.% to 0.034 wt.%.

Silicon-bearing phases showed notable variability between conditions. High-silicon (>40% Si) phases ranged from 0.002 wt.% to 0.327 wt.%, while low-silicon (<20% Si) phases ranged from 0.001 wt.% to 0.069 wt.%. Aluminium-bearing phases were identified in all samples except Condition 3. High-aluminium (>20% Al) phases ranged from 0.000 wt.% to 0.013 wt.%, medium-aluminium (5-20% Al) phases ranged from 0.000 wt.% to 0.024 wt.%, and low-aluminium (<5% Al) phases ranged from 0.000 wt.% to 0.018 wt.%. Minor oxygen-bearing and other trace phases were also recorded in all samples at abundances generally below 0.025 wt.%. Figure 5 provides a comparative assessment of the five manufacturing conditions, highlighting differences in the proportion of platinum-ruthenium present within the analysed areas and, consequently, differences in the overall abundance of impurity phases identified by automated SEM analysis.

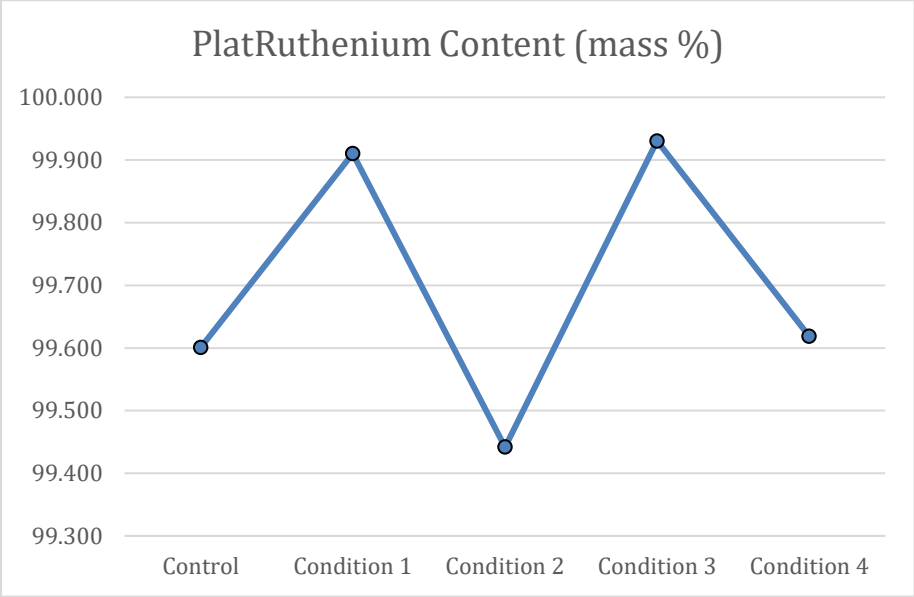


Figure 5. Platinum-ruthenium abundance determined by autoSEM-based process mineralogical analysis for the Control sample and Conditions 1-4.

4. Discussion

4.1. Integration of Manual SEM and Automated Mineralogical Analysis

The investigation demonstrates the value of combining conventional SEM-EDS analysis with automated SEM-based process mineralogy for the evaluation of platinum-ruthenium

jewellery products. While both techniques utilise the same analytical platform, they address different stages of the investigation and provide complementary information.

Manual SEM-EDS analysis was effective for the rapid identification and characterisation of impurity features within the platinum-ruthenium alloy. The technique enabled individual particles to be located and chemically characterised, providing insight into the range of impurity populations present within the material. By identifying the elemental signatures associated with these impurity features, the analysis provided evidence that could be used by the manufacturer to evaluate potential contamination sources and implement corrective actions within the manufacturing process. However, manual SEM analysis is inherently limited by the relatively small number of particles that can practically be examined. Although highly effective for identifying and characterising impurity populations, it is not ideally suited to quantitative comparison between different process conditions.

Automated SEM-based process mineralogy addressed this limitation by enabling statistically representative areas of material to be analysed. This provided quantitative measurements of impurity abundance and allowed direct comparison between products manufactured under different conditions.

Together, the two approaches formed a sequential workflow in which manual SEM-EDS was used to identify impurity populations and automated mineralogy was used to quantify their occurrence.

4.2 Nature of the Impurity Populations

The manual SEM investigation demonstrated that impurity features within the platinum-ruthenium alloys were compositionally diverse. Some particles were strongly enriched in carbon, while others contained varying proportions of oxygen, silicon, calcium, aluminium, sodium, chlorine, and iron.

The elemental signatures identified by SEM-EDS provided valuable information regarding potential contamination pathways and supported the manufacturer's investigation into likely contamination sources. Carbon-rich impurity particles were considered consistent with contamination associated with graphite mould materials and carbon-containing protective coatings used during the melting and casting process. The identification of these particles supported the evaluation of alternative coating systems during subsequent process optimisation trials.

Several impurity particles contained elevated concentrations of aluminium and silicon. These elemental associations showed strong similarities to the composition of the crucible materials used during production and were therefore considered indicative of crucible or refractory wear. Based on these observations, the manufacturer implemented changes to crucible management practices, including modifications to protective coatings and a reduction in the number of production cycles permitted before crucibles were removed from service.

Calcium-bearing phases were also identified within the impurity population. The presence of calcium is consistent with lime-based fluxes used during upstream platinum-group-metal processing, where lime and limestone are routinely employed during smelting operations and slags (Jones, 1999; Nell, 2004). These phases may therefore represent residual contamination inherited from earlier refining stages rather than contamination introduced during jewellery manufacture.

The occurrence of sodium- and chlorine-bearing particles on worked surfaces further suggests that some impurity populations may be associated with downstream fabrication, cleaning, or finishing operations. Collectively, these observations demonstrate how SEM-EDS analysis can provide actionable information to support contamination-source investigations and process improvement initiatives.

4.3 Evaluation of Process Modifications

One of the principal advantages of the automated SEM workflow was the ability to compare products manufactured under different process conditions.

Although all samples contained greater than 99.4 wt.% platinum-ruthenium, the automated analyses revealed measurable differences in impurity abundances between conditions. Variations were observed in the occurrence of carbon-bearing, calcium-bearing, silicon-bearing, and aluminium-bearing phases, demonstrating that changes implemented during production can influence the impurity population present within the final rolled product.

The use of predefined analysis areas ensured that the comparisons were made on a consistent basis and that differences between samples could be quantified objectively. This provides a useful framework for evaluating future process changes and consumable selections. The automated SEM workflow transformed the investigation from qualitative contamination identification to quantitative process evaluation. By analysing equivalent square sections under different manufacturing conditions, statistically robust comparisons could be made between process configurations. This enabled direct evaluation of the effect of individual process modifications on impurity abundance within the final rolled product. The comparison of process conditions provided the manufacturer with an objective basis for selecting manufacturing practices associated with lower impurity abundances. Based on the results, process conditions demonstrating improved contamination control were adopted for ongoing production, while modifications associated with increased impurity populations were discontinued. The study therefore demonstrates the value of automated SEM-based process mineralogy as a practical decision-support tool for process optimisation and quality assurance within platinum jewellery manufacture.

4.4 Application of Process Mineralogy to Jewellery Manufacturing

Process mineralogy has traditionally been applied to ore characterisation, concentrator optimisation, and metallurgical troubleshooting. The results of this study demonstrate that the same analytical principles can be applied successfully to high-value manufactured products.

The combination of rapid SEM characterisation and quantitative automated mineralogical analysis provides manufacturers with a practical tool for identifying impurity populations, monitoring process performance, and evaluating the effectiveness of process modifications.

The approach is particularly valuable where impurity levels are low and where traditional quality-control methods may struggle to identify or quantify contamination sources. Consequently, process mineralogy represents an effective quality-assurance methodology capable of supporting continual improvement within platinum jewellery manufacture.

5. Conclusion

Manual SEM-EDS and automated SEM-based process mineralogical analysis were successfully applied to the investigation of impurity populations within platinum-ruthenium jewellery alloys.

Manual SEM analysis enabled rapid identification and characterisation of impurity features occurring both within the alloy matrix and along worked surfaces. The investigation revealed a range of impurity populations exhibiting diverse compositions, including carbon-rich particles and features containing varying proportions of oxygen, silicon, calcium, aluminium, sodium, chlorine, and iron.

Automated SEM-based process mineralogy provided quantitative assessment of impurity abundance over statistically representative sample areas and enabled direct comparison between products manufactured under different process conditions. Platinum-ruthenium was confirmed as the dominant phase in all samples, accounting for between 99.44 and 99.93 wt.% of the analysed material.

The combined analytical approach demonstrated measurable differences in impurity populations between manufacturing conditions while maintaining consistently high platinum-ruthenium contents. The methodology therefore provides an objective means of assessing process modifications and monitoring contamination within platinum jewellery products.

This study demonstrates that process mineralogy can be successfully extended beyond traditional mining and metallurgical applications into downstream manufacturing environments.

6. References

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