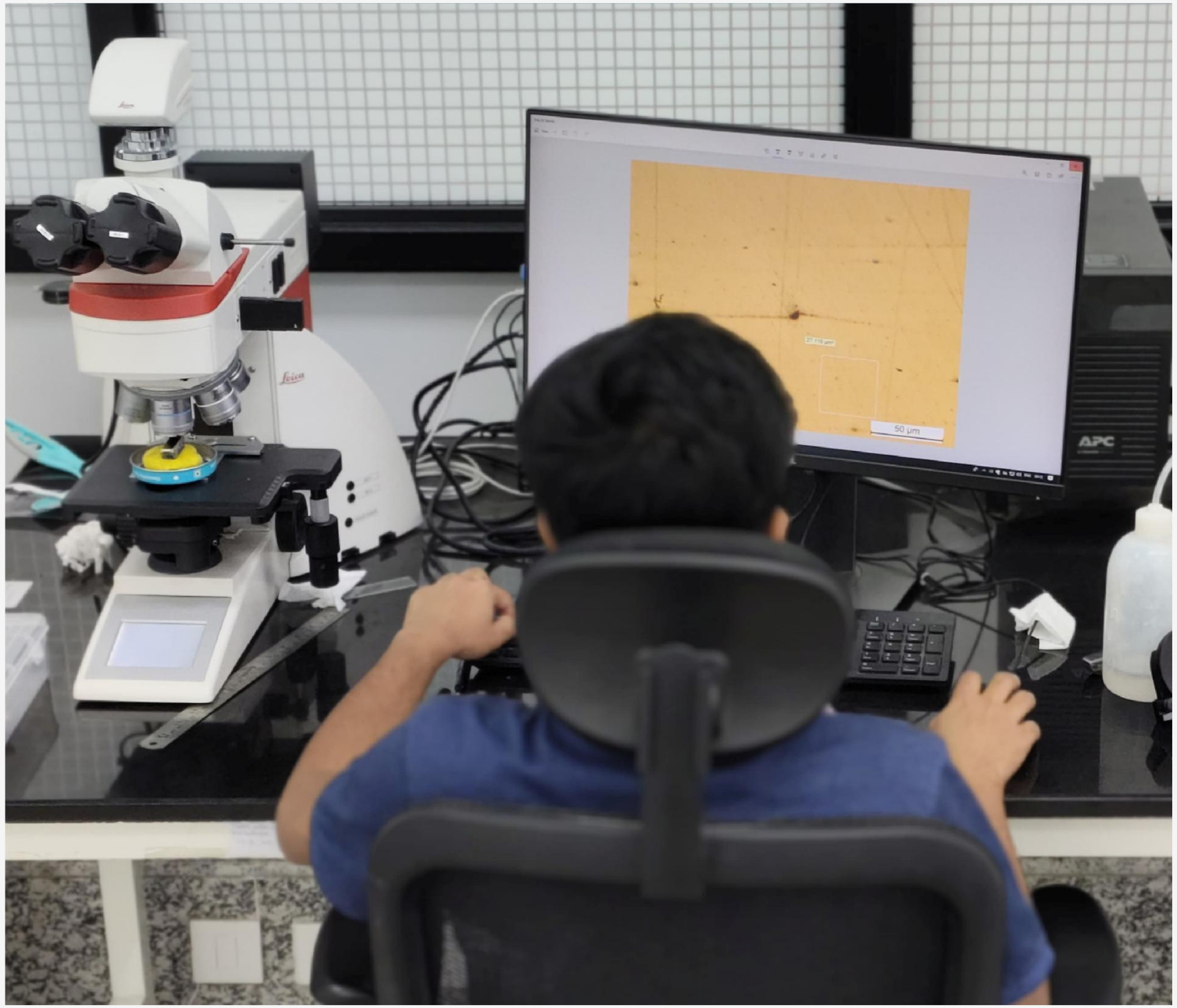
Cleanliness of Automotive Steels



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Introduction

The problem statement revolves around the presence of non-metallic inclusions in steel.

Under torsional fatigue conditions, these inclusions significantly affect the fatigue life of components, often becoming initiation sites for cracks that lead to premature failure.

For this semester, our focus was to:

- Understand the classification and types of non-metallic inclusions, and
- Collect inclusion data as directed by the industry partner.

The ultimate goal is to minimize harmful inclusions and enhance the overall cleanliness of steel, leading to improved performance in real-world automotive applications.

Literature Review

What is Inclusion?

Inclusions are non-metallic particles that are unintentionally or intentionally present within a metal matrix, especially in steel. They are typically formed during melting, solidification, or secondary processing due to reactions between alloying elements and impurities like oxygen, sulphur, or nitrogen.

Classification of Inclusions

Endogenous Inclusions : Formed by chemical reactions within molten steel, these include:

Deoxidation products: Oxides like alumina (Al_2O_3) and silica (SiO_2) formed from reactions with aluminium or silicon.

Precipitated inclusions: Sulphides (MnS) and nitrides (TiN) that crystallize during cooling.

Exogenous Inclusions : Introduced from external sources, these include:

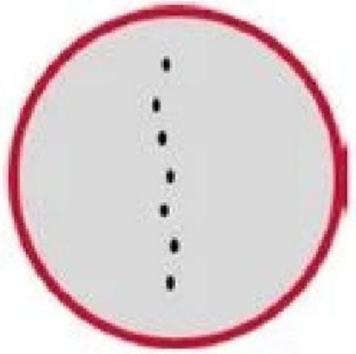
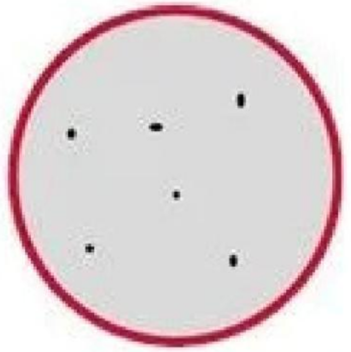
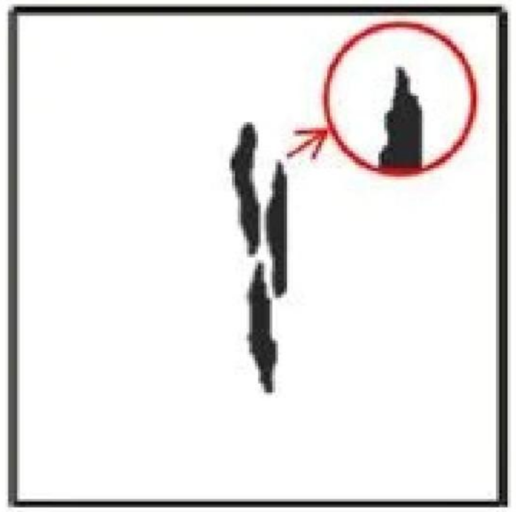
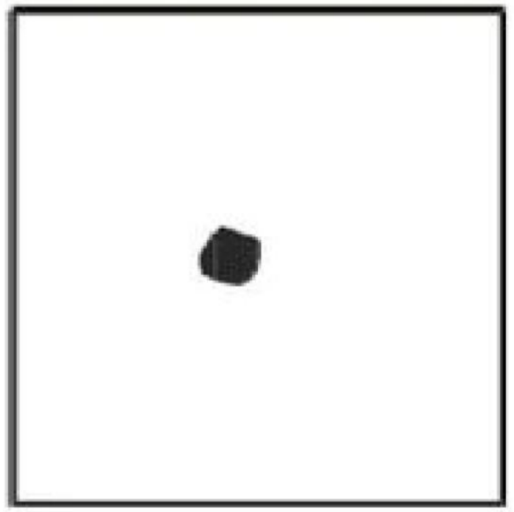
Slag entrapment: Calcium or magnesium oxides introduced by turbulent mixing.

Refractory erosion: Fragments from furnace linings or casting molds that get embedded in the steel.

Classifying Inclusions:

Both ASTM and ISO standards use the Type A to D nomenclature assigned to sulphides, aluminates, silicates, and globular oxides, but each inclusion type is further categorized as thin or thick/heavy according to their width.

Source : https://www.leica-microsystems.com/sciencelab/applied/rate-the-quality-of-your-steel-free-webinarand-report/

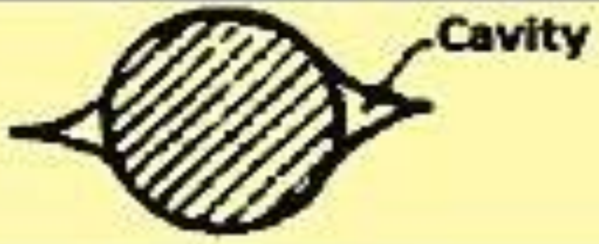
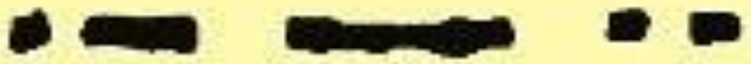
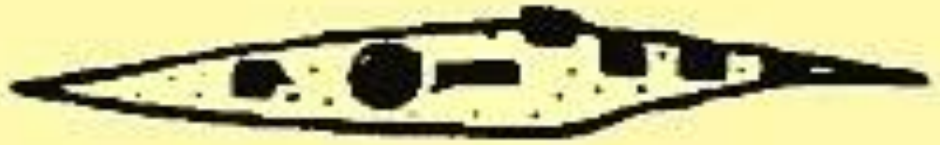
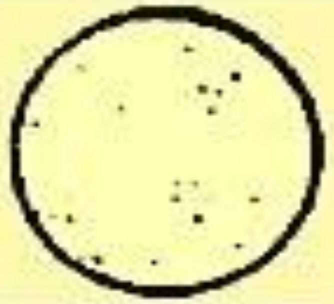
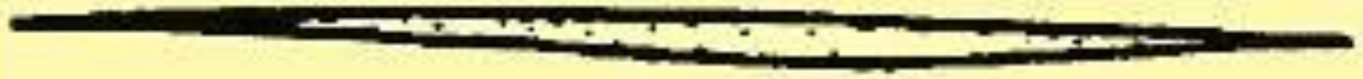
Sulfides (gray color)	Oxides (black/dark gray color)		
			
Type A These inclusions are light gray in color and highly deformable sulfides. They show a broad range of aspect ratios depending on the steel processing method, but maintain rounded contours and tend to remain isolated particles in the microstructure.	**Type B** These inclusions are aluminate oxides having angular contours and an aspect ratio of 3 or less. They are frequently found in clusters of 3 or more particles.	**Type C** These inclusions are silicate oxides having a variable dark gray tone and pointed ends. They are usually grouped in small numbers due to their highly deformable nature.	**Type D** These inclusions, globular oxides, are the most easy to recognize.
Sulfides Gray, highly deformable, variable AR, elongated, rounded contours, isolated	**Aluminates** Black, non-deformable, AR < 3, angular, grouped (n ≥ 3)	**Silicates** Black/dark gray, highly deformable, AR ≥ 3, elongated, pointed ends, isolated or grouped (n ≤ 3)	**Globular** Black, non-deformable, AR ≤ 3, angular or circular, isolated, (DS type, diameter ≥ 13 µm, ISO 4967 [10])
			

Difference between ASTM Standard and Japanese Standard

The **ASTM standard** (like ASTM E45) measures inclusion size based on the **longest diameter** of the inclusion seen under a microscope. It classifies inclusions by type and severity, offering a detailed view of their shape, size, and impact on properties.

The **Japanese standard** (like JIS G 0501) measures inclusion size using the **equivalent diameter**, which is the diameter of a circle with the same area as the inclusion. It focuses more on overall size and distribution, with less emphasis on specific inclusion types.

Behaviour of inclusions during deformation

Type	Description	Before rolling	After rolling
(a)	A hard inclusion under rolling conditions		
(b)	A hard crystalline inclusion broken during rolling		
(c)	A hard inclusion cluster strung out during rolling		
(d)	An inclusion composed of hard crystals dispersed in a soft matrix		
(e)	A soft inclusion under rolling conditions		

Source : https://images.app.goo.gl/oLktCqB6PSHUgfz99

Inclusion Rating

Inclusion rating is a measure of the type, size, number, and distribution of non metallic inclusions (like oxides, sulphides, silicates) in a metallic material, usually steel.

It helps assess the cleanliness of the metal and its suitability for critical applications (e.g., automotive, aerospace).

Higher inclusion ratings mean more or larger inclusions, which can reduce strength, fatigue resistance, and overall performance.

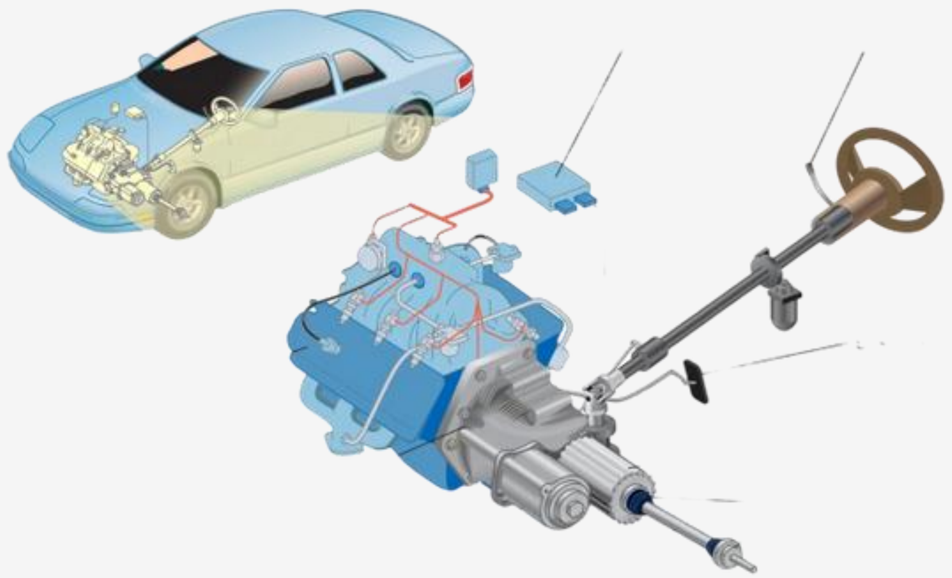
Why is cleanliness of Automotive steels crucial ?

Cleanliness in automotive steels is crucial for ensuring high fatigue strength. Non-metallic inclusions can act as stress concentrators and initiate cracks under cyclic loading. This is especially important in components like Suspensions, Axles and Shafts that experience repeated stress during driving. Cleaner steel ensures better durability and reliability, which directly impacts vehicle safety and performance.

Another reason cleanliness matters is for improved formability and surface finish. Inclusions can cause surface defects and cracks during stamping or bending operations, leading to manufacturing defects or rejection of parts. Clean steel allows for smoother processing, better weldability, and high-quality surface coatings. This is essential not only for corrosion resistance but also for maintaining the aesthetics and longevity of the vehicle.

How inclusions affect properties?

Parameter	Effect of Inclusions
Fatigue Life	Inclusions initiate microcracks under cyclic loads, significantly reducing life
Toughness	Sharp inclusions reduce ductility and increase brittleness
Fracture Mechanics	Inclusions lower fracture toughness and increase crack growth rate
Surface Sensitivity	Surface-near inclusions are more harmful due to tensile stress exposure



Methodology

1.Sample Preparation

- Grinding: Used successive grades of SiC paper (220 to 1500 grit).
- Polishing: Used Alumina Paste Grade 1 for final cloth polishing.
- Cleaning: Used in ethanol to remove polishing debris.

Ethanol is used instead of water to avoid reacting with sulphide inclusions, as water can oxidize or dissolve them in high-sulphur steels.

Methodology

3. Extreme Value Analysis

Automotive Steel components subjected to torsional stress (such as drive shafts, transmission parts, and axles), the presence of non-metallic inclusions plays a significant role in fatigue initiation and failure.

- Extreme value analysis (EVA) focuses on the largest inclusions in the steel matrix because:
- The largest inclusion is statistically the most likely to initiate failure. It acts as a
- stress concentrator, especially under cyclic or multiaxial stress conditions like

torsion.

- According to fracture mechanics principles, crack initiation often occurs from the largest defect, even if the overall inclusion content is low.

4. Data Collection

- Type and composition of steel
- Sample location and preparation method Microstructure and inclusion morphology
- Inclusion count, size distribution, and largest inclusion size
- Rating per relevant standard

Sample Id	Inclusion size (µm^2)	
	Location 1	Location 2
Sample 1	44.387	60.265

Results - Image Analysis

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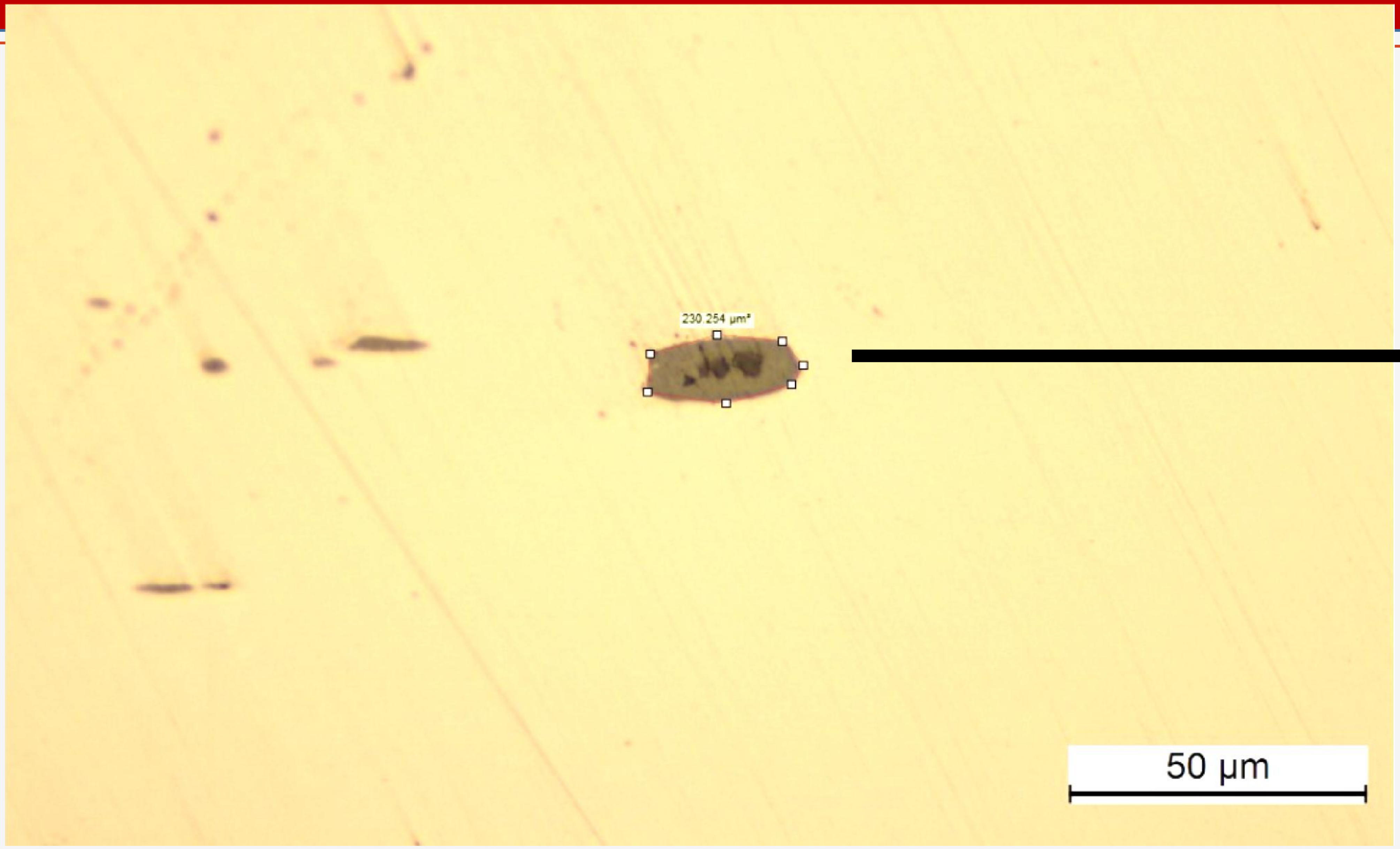
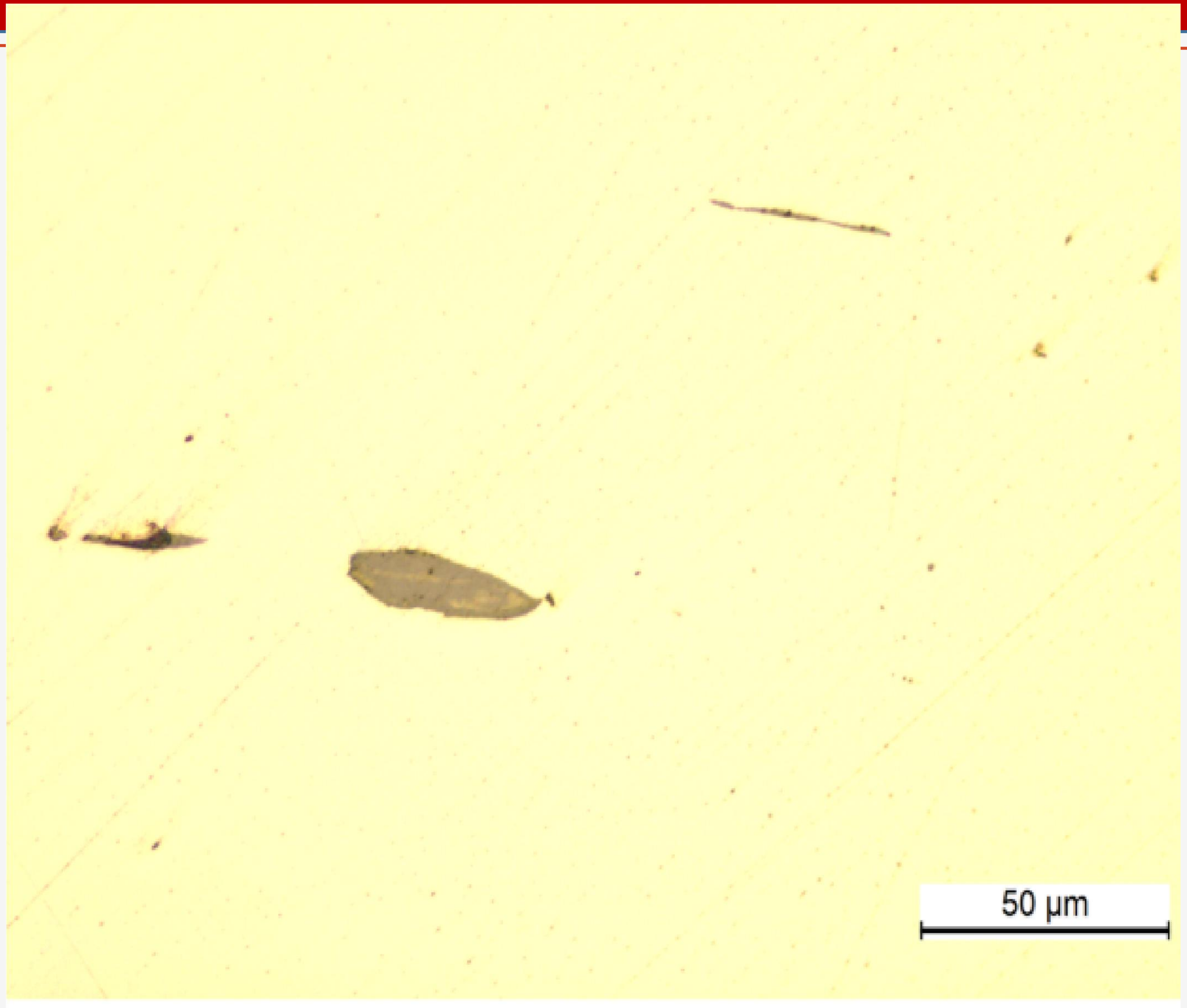


Complex Inclusion

An Inclusions composed of hard crystal Type D dispersed in soft matrix Type A

Results - Image Analysis



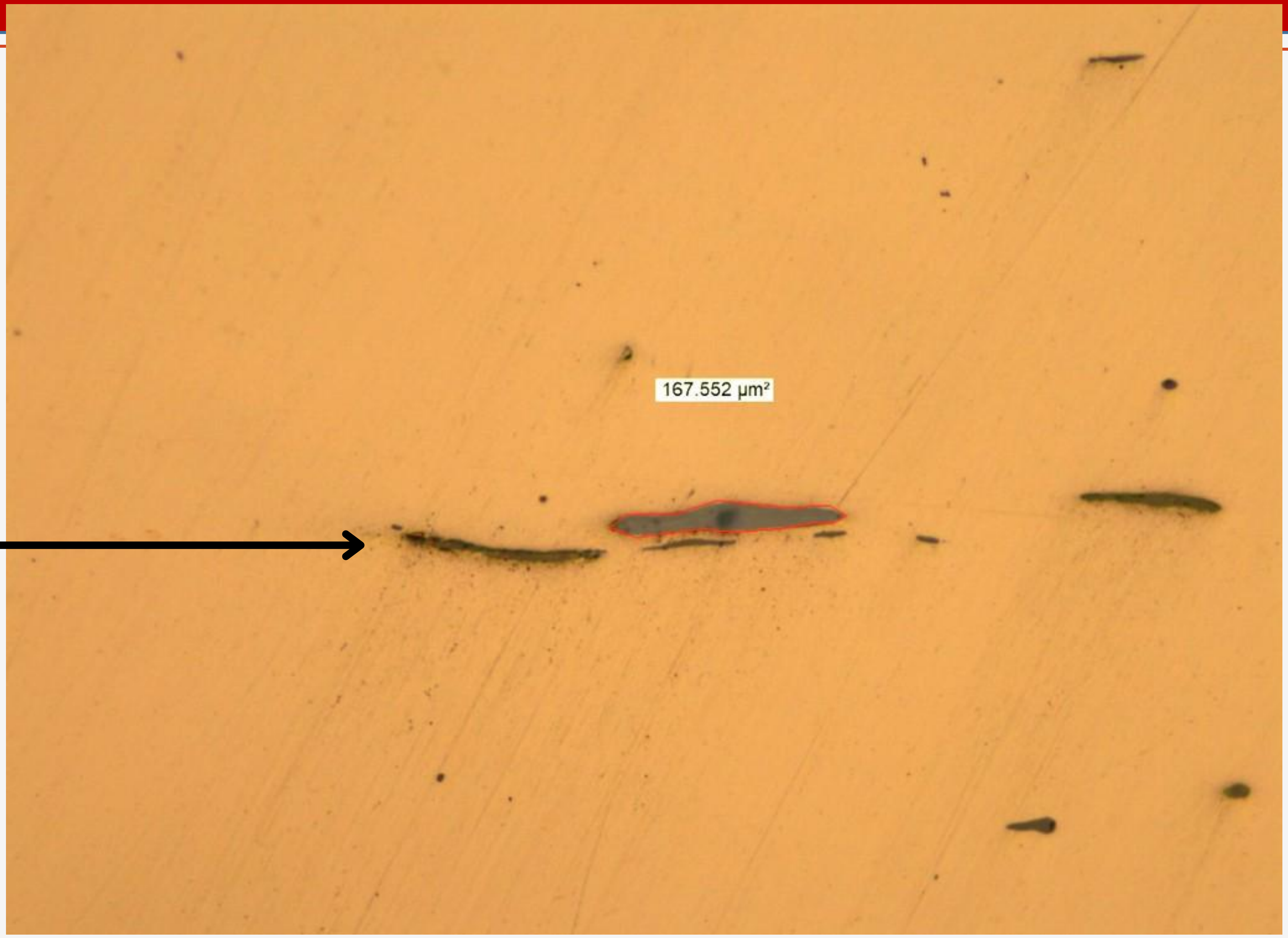
Type A - Sulphide Inclusion

Results - Image Analysis

Type B - Aluminates Inclusion

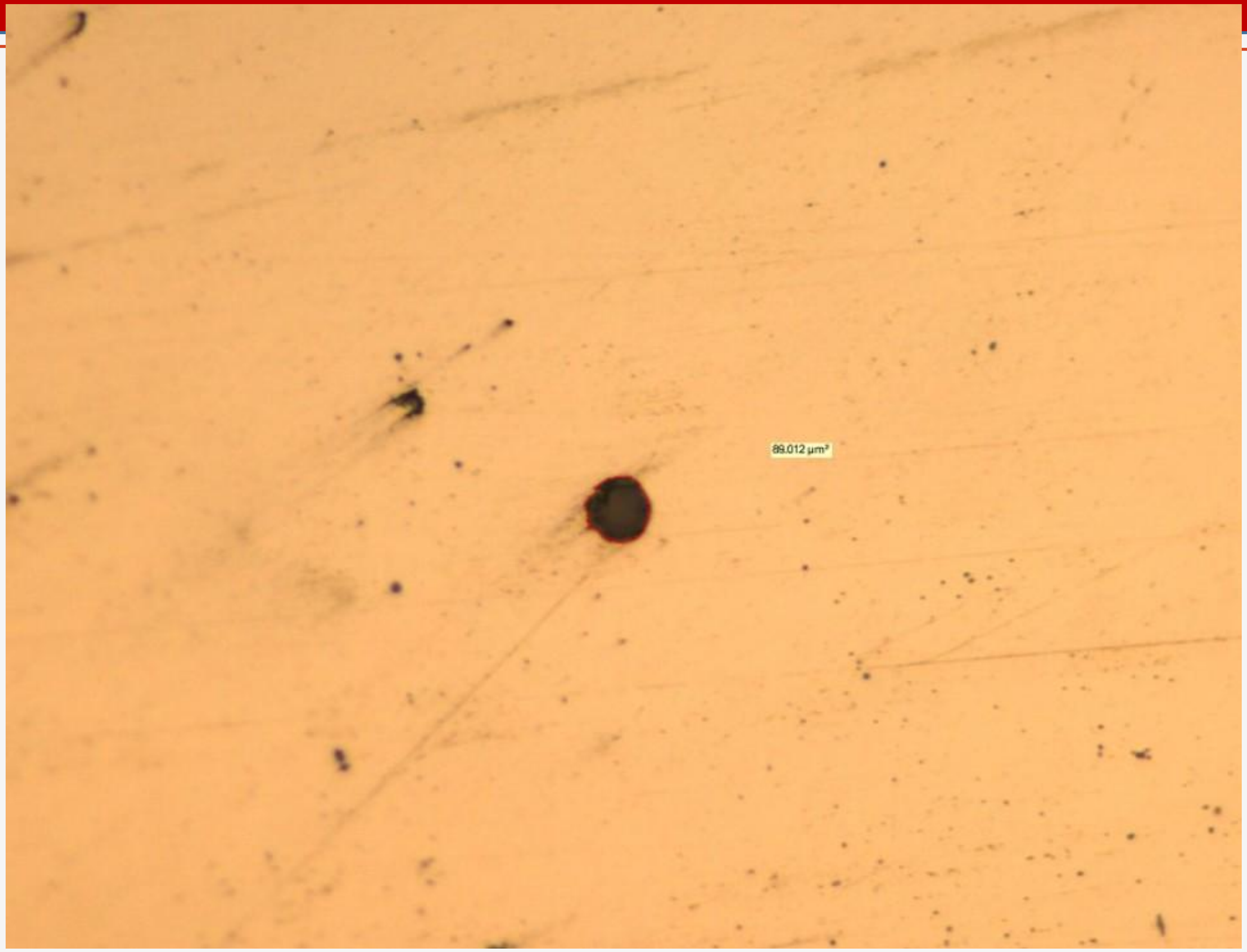
Results - Image Analysis

Type C - Silicates Inclusion



Complex Inclusion

Results - Image Analysis



Type D - Globular Oxide Inclusion

Summary and conclusions

We understood the importance of inclusion removal and its impact on properties like strength, fatigue resistance, and surface quality. Inclusions can act as defects and reduce steel reliability.

- Collected data through metallography and microscopy to study inclusion characteristics.
- The data will be used to build a statistical model for deeper analysis.
- Aim is to observe trends and correlations between processing parameters (e.g., pouring speed, oxidizing agents) and inclusion size.
- This will help optimize process conditions for improved steel cleanliness and performance.

Thank you