

Technical Cleanliness Process and Analysis for Aluminum Die Cast Component used in Automotive Applications

Sumit Shukla

(Post Graduate in Computer Aided Tool Engineering & B. Tech in Mechanical Engineering)

ABSTRACT : *The growing complexity in interfaces of today's technical products, especially within the aerospace, automotive, heavy equipment, and electrical engineering industries, has resulted in an increasingly high demand for product reliability and quality assurance. More efficient components and systems, increasing warranty claims and the reduction in start-up breakdowns are steadily driving up the demands for cleanliness management and cleanliness monitoring of production components. What started in the 90's with just a handful of components under the term of "residual contamination" has evolved since the year 2000 to become a key measure of quality in the automotive and supplier industries under the new name of "technical cleanliness. This paper explains the detailed Technical Cleanliness Process as per Automotive Industry Standards and also focusses on detailed inspection and analysis process used to verify the Technical Cleanliness Requirement of a Aluminum Die Cast component used in automotive applications.*

KEYWORDS – Durability, Gravimetric Analysis, Particle, Surface Tension and Vibratory Process.

I. INTRODUCTION

Component cleanliness refers to the absence of particles on components which might otherwise impact downstream production processes and/or adversely affect the performance of a product.

Even the smallest amount of residue may increase the risk of failure on electromechanical components significantly. Therefore, say when producing electronic boards, you should intend to keep the number of particles with a potential risky size and type as low that no failures occur during the production process nor when the board is applied in the field later.

Metallic particles, for example, may cause short circuits and non-metallic particles may impair the correct assembly of circuit boards.

The risk increases more when we have a control module which is assisting steering system and is classified as safety critical product.

The term 'technical cleanliness' was coined by the automotive industry to address particle related system interruptions in the automotive industry. In contrast to 'optical cleanliness', which relates to the cosmetic or visual appearance, e.g. vehicle coating, technical cleanliness always refers to the performance of components, assemblies and systems.

Particulate contamination in the automotive industry is often not limited to a certain area but may migrate from a previously non-critical to a sensitive location and hence impair performance.

Therefore, the cleanliness requirements of the automotive industry often apply to complete systems, whereby the most particle-sensitive component (weakest link in the chain) determines the cleanliness level and admissible limiting values for the entire system and all components within it.

The durability and lifecycle of a finished product depend on several characteristics, all of which contribute to its measurable technical cleanliness:

- Quality and characteristics of the product material.
- Fitting tolerances.
- Overall cleanliness of a surface or particle load.

If we consider any automotive production line, manufactured metal parts are processed, including cutting, grinding, and deburring. Serious, system-wide problems can occur if metal chips and other foreign matter produced during the manufacturing process are not properly cleaned and removed from critical systems (e.g., crankshaft bearing clamps, valve blockages, nozzles, injectors, filters, or electronic parts). The entire system is subject to failure if any part of the fuel

system, braking system, hydraulic circuit, or electronics doesn't meet cleanliness requirements. For instance, the coolant flowing through a radiator's tube helps cool an automobile's engine. If contaminants are left inside the tube when a radiator is manufactured, it may decrease cooling efficiency and even damage the engine. The inside of the tube must be thoroughly cleaned throughout the manufacturing process, and the cleanliness level rigorously inspected.

As another example, a brake caliper houses a piston that acts as a clamp to press the brake pad against the rotor, and the movement of the piston is essential to proper brake function. To help ensure that the piston functions properly, the area inside the brake caliper must be very clean. The piston unit is completely sealed to prevent contaminants from interfering with the action of the piston. This is especially important since many contaminant particles are produced as the brake pad wears down. Cleaning is one of the most important steps in the caliper manufacturing process, and inspectors must monitor each part's cleanliness to prevent metal chips from contaminating the caliper.

II. TECHNICAL CLEANLINESS STANDARDS

Although the term 'technical cleanliness' was coined by the automotive industry, the technical cleanliness standards have also been increasingly adopted by other industries such as medical technology or the optical industry. Automotive Industry generally uses the technical cleanliness guidelines as per VDA 19 and ISO 16232 standards. These guidelines propose a system for designing and implementing component cleanliness analyses to enable quantifiable comparisons of component cleanliness levels. However, these standards in general does not specify any limiting values for component cleanliness. These must be defined according to component function, producibility and verifiability.

Limiting values for component cleanliness ensure component performance and should be defined as early as possible during the component development stage.

The following possible malfunctions should be considered:

- electrical short circuit
- ingress protection and interface clearances
- electrical insulation of contacts
- impairment of optical systems such as cameras
- reduced wettability/solderability
- mechanical obstruction
- increased or reduced friction
- increased or reduced power
- leaks
- ...

In general, automotive industries have their product specific checklist form to verify the possible malfunctions and failure modes to derive the limiting values and class. The sentence "as clean as necessary, not as possible" should be considered to fulfill economic requirements and in this regard, it is important to state, that surfaces can never be free of contamination for 100%.

Refer below Classification table generally used for particle size definition limiting values. From here only we have the limiting values extracted for the component requirements.

This guideline applies to the manufacture of electric, electronic and electromechanical components, circuit boards and electronic assemblies that are produced with state-of-the-art standard production methods and describes the resulting level of technical cleanliness that can be expected from the product and processes.

This guideline is a reference document which serves to illustrate the technically feasible options and provide a basis for customer and supplier agreements. It is not intended to be regarded as a specification or standard, its primary focus is on component cleanliness about loose or easily detachable particles.

III. CASE STUDY: ALUMINIUM DIE CAST COMPONENT

To have a better view let us consider an Aluminum Die Cast component used in an automotive application. This component is a child part of a product which is a control module and includes plastic connectors integrated with it. Alloy of the component is AlSi9Cu3 (Fe).

The component has two critical areas to be considered in our Technical Cleanliness planning: -

1. (Fig.4) The component has one functional surface (highlighted in green) which forms interface with electronic board by thermal paste. Means this surface must be free from any metallic particles and must have good surface texture (roughness and surface tension) for good bonding with thermal paste.
2. (Fig.5) The component also has features (x3 places) to be machined (face milling and tapping) post die-cast process. This machined interface in the component will be used for vehicle mounting. These machined features are highlighted in blue.

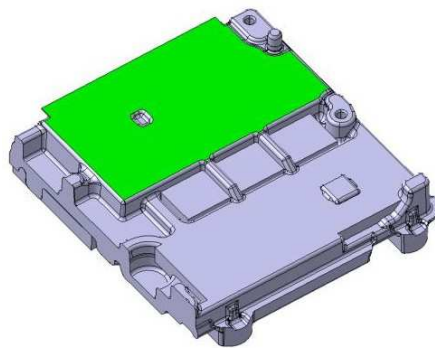


Fig.1: Functional surface (green)

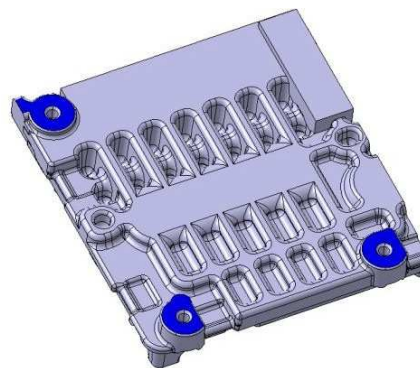


Fig.2: Component mounting features (blue)

Refer below Fig. 6 for the Basic Process Steps to manufacture the above component.

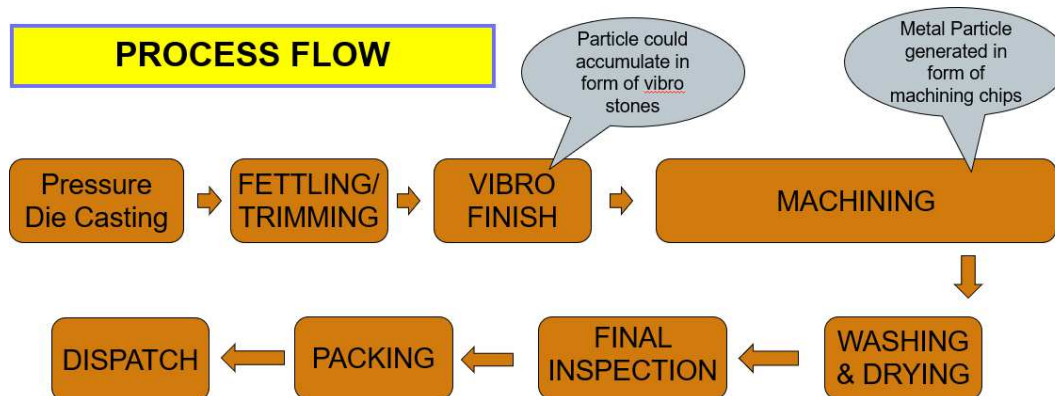


Fig.3: Process Flow Diagram

After we have the initial shot from Pressure Die Cast Tool then we will de-gate the component (trimming) to move for finishing process which is Vibratory Finishing. Post finishing, we will machine (facing and tapping) the vehicle interfaces and then proceed for Washing Process to remove the particle contamination followed by final inspection, packing and dispatch.

In the manufacturing process prime step is to identify the process steps which could lead to particle contamination (metallic or non-metallic any). We could clearly see that we have three main possibility in process flow to have the particle contamination: -

1. **Vibratory Finishing:** A vibratory finishing process consists of placing parts, media and compounds into a vibratory tub or tumbler. The vibratory action creates a force on the parts causing media and parts to turn and grind against each other deburring or polishing a mass of parts. Refer below Fig.7 for the equipment generally used and to understand the general principle. From the process we understand that there is a chance that the vibratory particles used could contaminate or get stuck in the component features.

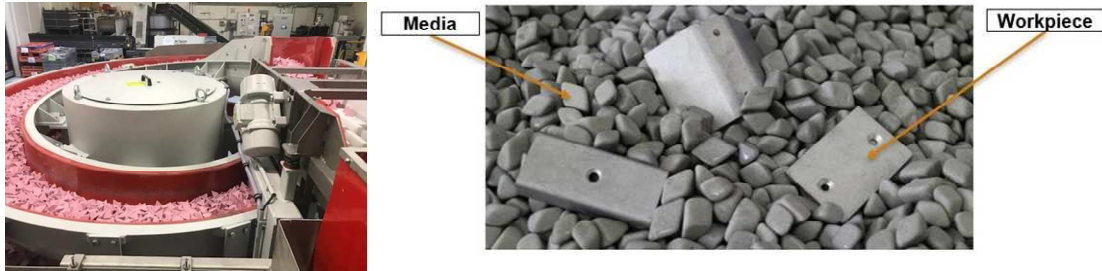


Fig.4: Equipment and Principle

2. **Machining Process:** As you know the component has features which need to be machined which includes face milling and tapping. This is clear that machining will for sure generate metallic chips which are very critical if not removed or remains unaddressed later.
3. **Handling:** Organic contamination is also possible while handling of the component throughout the process flow. If not taken care particle could contaminate in manual material movement and even at packaging stage during before final dispatch.

Considering all above possibilities, we now try to build a robust technical cleanliness concept in coordination with the die cast manufacturer to address the possible contamination as per above process flow diagram.

Refer points which need to be considered to have a controlled process and to avoid the particle contamination at any of the stage from start to end. These controls measures need to be initiated by the die cast manufacturers and to be verified by the product developed or end customer. In the end the controls are integrated into final process flow diagram and control plan of the manufacturer.

1. Care in selection of vibratory media to avoid any stuck up in small component features
2. Proper drier media (corn-corb) to help removing vibro stains and assist drying
3. Inspection to be done after vibratory finish process based on defect checklist
4. Proper drying system after washing process
5. Material movement after washing / drying process to be in enclosed environment to avoid any organic contamination
6. Visual inspection on final component based on defect checklist

Refer below detailed Process Flow Chart where we try to integrate the various controls based on the material movement and operations step-wise.

Operations in RED box are possible steps which could lead to particle contamination including the Manual Handling. Operations highlighted with YELLOW are checkpoints included to verify the Visual defects and particle contamination. Operation No. 100 includes Millipore Test to analyze the contamination weight based on extraction method.

STEP	OPN. INSP.	OPN.	MOVEMENT	INSPECTION	STORAGE	OPERATION CODE	DESCRIPTION
1					△	10	Option 1) Receive Aluminium Alloy ALSi9Cu3 (Fe) from supplier & store in Raw Material Store. Or Option 2) Receive molten material from supplier & store in Material Storage Area
2				◇		20	Option1) Inspection of ALSi9Cu3 (Fe) (chemical composition) as per specification or Option 2) Inspection of Molten material received from supplier(material composition) as per MCS 01
3			⇒			25	Transfer of raw materials to central melting furnace
4	◇					30	Option 1) Melting of ingots on Central Melting Furnace and Degassing, Vacuum test of metal & Inspection (Material composition) as per MCS-01 Option 2) Degassing & vacuum testing of molten material received from Supplier
5			⇒			35	Material move to holding Furnace.
6	◇					40	High Pressure die casting at 400T & inspection
8		○				50	Trimming/Fettling
9		○				60	Vibro & drying
10				◇		70	Casting Inspection
11	◇					80	VMC machining & Inspection
12		○				90	DMC Marking
13	◇					100	Washing & Millipore Test
14				◇		110	Final Inspection
15		○				120	Packing of Material
16			⇒			125	Movement of material to finish goods area
17					△	130	Storage of finish goods
18				◇		140	PDI of the finished material
19			⇒			150	Material Dispatch to Customer

Fig.5: Detailed Process Flow Diagram

IV. DRAWING DEFINITIONS FOR TECHNICAL CLEANLINESS

In the past, drawings usually contained rather general information on component cleanliness, which was not systematically verified.

Example: Parts must be free from contamination e.g. swarf, release agents, grease, oil, dust, silicone...

With the publication of VDA 19/ISO 16232, standardized cross-company procedures were defined to record, analyze and document component cleanliness information.

For our case here, we consider an Aluminum Die Cast component used in an automotive application to for more clear view and understanding. Following details are generally included in the component Drawing of this component to verify the Technical Cleanliness Requirements towards the die-cast component manufacturer. The manufacturer will agree on the drawing requirements and provide the inspection report for the Technical Cleanliness verification. For drawing definitions, we considered the below main attributes which could impact on the Product functionality: -

1. **Surface tension of the functional surface of the component which could impact the overall product performance**

Drawing Note: - Surface Tension: 32 mN/m minimum on the functional surface

2. **Quantity of Metallic and Non-Metallic Particles as per standard to avoid any short-circuit or low product performance**

Drawing Note: - Technical Cleanliness Definition table as per VDA 19 and ISO 16232 to be given in the drawing. Refer below: -

Specification according to ISO 16232 & VDA 19	Specification for N components N=1				Gravimetry per part [mg]
	Class	Size x [μm]	Max. quantity of particles		
			metallic	non metallic	
H	$200 \leq x < 400$	20	30	$G_c \leq 0.5\text{mg}$	
I	$400 \leq x < 600$	5	10		
J	$600 \leq x < 1000$	0	1		
K	$1000 \leq x$	0	0		

Fig.6: Technical Cleanliness drawing definition example

3. **General surface requirements which the die cast manufacturer will consider while visually inspection the finished parts**

Drawing Note: -

Surface requirements:
 Visible corrosion, burrs, flashed adherences, adhesive chips not allowed.
 During part manufacturing, grease, silicone based components or medias, mold parting agent are not allowed during the whole production process.

Fig.7: Technical Cleanliness drawing general surface note example

Verification Method for each of the above attribute is given below: -

1. Surface tension

To be checked by surface tension ink test pen



Fig.8: Surface Tension Measurement using Ink Test Pen

General Process Below: -

- Determine surface tension using ink test (suppose 32mN/m)
 - Applied ink film must persist for 2 seconds
 - Value is deemed not achieved if the ink gathers to form droplets
 - Test area must not be touched!
2. Technical Cleanliness Inspection to be done as per VDA 19 and ISO 16232. Refer next section of paper for detailed analysis method and results.

- General surface requirements will be considered while visually inspection the finished parts and must be mentioned in the inspection checkpoints. Operators must be trained to visually identify the defects as per master sample.

V. TECHNICAL CLEANLINESS ANALYSIS AS PER VDA 19 / ISO 16232

Proper technical cleanliness inspection is based on a clear, established process that utilizes particle extraction on membrane filters to quantify contaminants that directly affect the performance, lifetime, and reliability of finished products. Particles are taken from sample components via flood, squirt, rinse, or ultrasonic bath, and then collected on a membrane filter. Once the filter is dried, it is then inspected using a multi-step inspection process to identify and analyze the contaminants in question.

The contaminants are analyzed in accordance with international standards such as ISO 16232 (VDA 19.1) and ISO 4407.

VDA 19 Part 1 defines a particle as a solid body composed of metal, plastic, minerals, rubber or a salt. Paste-like fractions are not considered to be particles.

Metallic particles: Metallic particles are particles that are primarily characterized by a shiny metallic, reflective surface. They can be detected through a combination of normal and polarized light imaging. An optical microscope with the relevant features normally suffices for identifying metallic particles.¹

Non-metallic particles: Non-metallic particles are particles that are not primarily characterized by a shiny metallic, reflective surface. They contain no fibers.²

Definition of fibers: Component cleanliness analyses invariably detect textile fibers from clothing, which are ubiquitous in any production or laboratory environment where people are present. Fibers are non-metallic particles, which, although usually mentioned in the test reports, are not considered in the evaluation.³

VDA 19 describes the application methods and conditions to determine and document particulate contamination. It also specifies the different extraction and analysis methods.

The following extraction methods are suggested for removing particles on electric, electronic and electromechanical components, circuit boards and electronic assemblies (hereafter referred to as 'components'):

- pressure rinsing
- ultrasonic techniques
- internal rinsing
- agitation
- air extraction

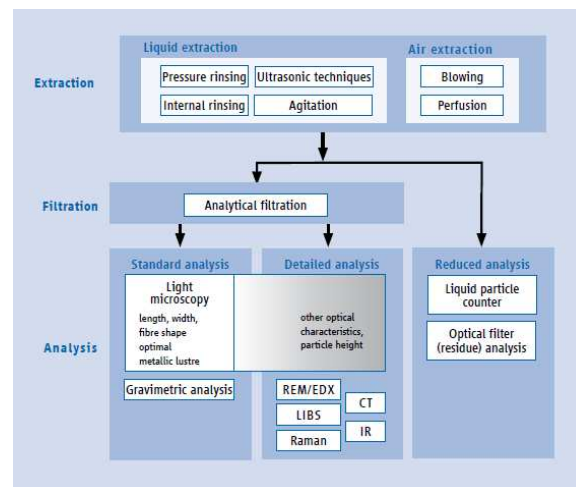


Fig.9: Test method as per VDA 19 Part 1

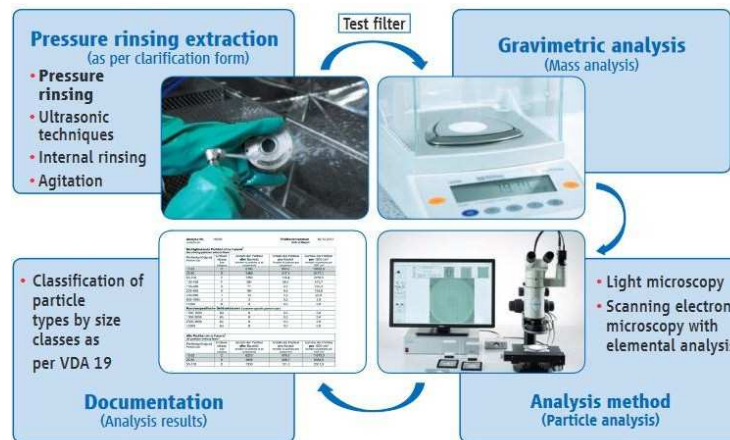


Fig.10: Technical Cleanliness Flow Diagram

Preparation

- Washing and Extraction
- Filtration
- Drying and Weighing

Inspection

- Image Acquisition
- Particle Detection
- Particle Size Measurement and Classification
- Particle Count Extrapolation and Normalization
- Contamination Level Calculation
- Cleanliness Code Definition
- Maximum Approval Check
- Separation of Reflective and Nonreflective Particles
- Fiber Identification
- Results Review
- Reporting

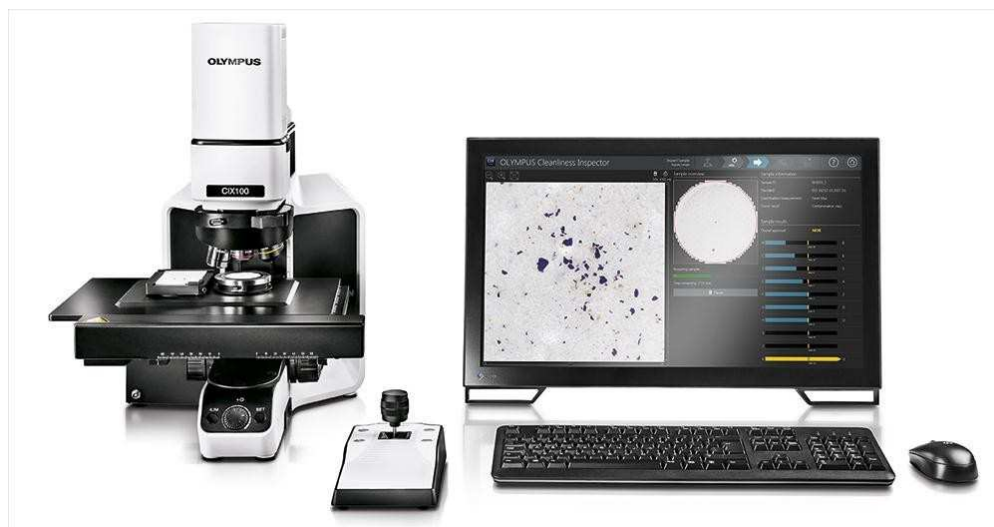


Fig.11: Technical Cleanliness Analysis setup (OLYMPUS CIX Series)

VI. TECHNICAL CLEANLINESS ANALYSIS RESULTS

Gravimetric Analysis Results: In our case we used Millipore Test to verify the particle weight against the limit mentioned in drawing. Manufacturers have long relied on membranes and devices from Millipore to evaluate the cleanliness of newly made parts by running the Millipore test (gravimetric analysis) to quantify the total mass and size of contaminating particles.

As per drawing Gravimetry mass is given as maximum 0.5 mg.

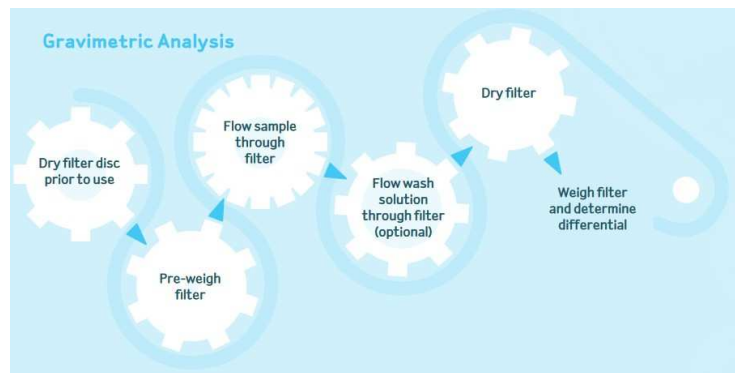


Fig.12: Gravimetric Analysis

Refer the Gravimetric Analysis result as checked for one sample after washing process through Millipore Test. Here we see Gravimetry value C which is $W_2 - W_1$ is 0.1 mg, so we conclude that gravimetry mass of the part is OK.


PART NAME: HEAT SINK		PART NO.			SAMPLE NO.
SPECIFICATION	WEIGHT IN mg			REMARKS	
SPECIFICATION OF CONTAMINATION (C)	DRY MEMBRANE (W1)	CONTAMINATED MEMBRANE (W2)	CONTAMINATION (C)	5 µm Membrane used	
1 Max. 0.5 mg	99.2 mg	99.3 mg	0.1 mg	ok	ok
SIZE IN mm					
SPECIFICATION OF SIZE					
1 MAX PARTICLES SIZE 1000 µm	0.267 X 0.261 mm				ok
MEMBRANE SAMPLE					
					

Fig.13: Gravimetric Analysis Report

Particle analysis Results: As per VDA 19 process flow diagram Gravimetric Analysis gives basic measure of contamination weight and particle size but does not refer to particle count and particle type as per our drawing

requirement. So, here we perform Particle Analysis through microscopic system to have complete view on particle count and type.

Refer below the apparatus used to perform Gravimetric Analysis and Particle Analysis for our aluminum die cast component as considered in case study.



SL. NO.	DESCRIPTION
1	PRESSURE VESSEL
2	VACUUM PRESSURE PUMP
	Vacuum Gauge: KI 934428
	Pressure Gauge: KI 934333
3	DRYING OVEN (Sl. No. 0617698)
4	SHIMADZU ANALYTICAL WEIGHING BALANCE, MODEL ATY 224, SL NO. D307534711
5	FILTREX OPTIMIZED - AUTOMATIC PARTICLE SIZE ANALYSIS SYSTEM

Fig.14: Equipment used for Aluminum die Cast Technical Cleanliness Analysis

Result Summary: -

Parameters	Specifications	Aluminium die cast component				
		Part 1	Part 2	Part 3	Part 4	Part 5
Gravimetry Analysis	Max 0.5 mg	0.1 mg	0.2 mg	0.1 mg	0.1 mg	0.1 mg
Evaluation of Metallic Particles						
Class H	200 – 400	2.0	1.0	0.0	0.0	3.0
Class I	400 – 600	0.0	0.0	0.0	0.0	0.0
Class J	600 – 1000	0.0	0.0	0.0	0.0	0.0
Class K	> 1000	0.0	0.0	0.0	0.0	0.0
Evaluation of Non-Metallic Particles (including fibers)						
Class H	200 – 400	5	2	2	6	3

Class I	400 – 600	2	0	0	0	0
Class J	600 – 1000	0	0	0	0	0
Class K	> 1000	0	0	0	0	0
Evaluation of largest Particle						
Metal particles	µm	234	323	178	174	235
Non-Metal particles	µm	590	235	298	292	252
Fiber Particle	µm	1210	2002	1310	1049	3118

As you can see Gravimetry Mass and particle count as per drawing is analyzed as per VDA and is Passed.

Evaluation of largest particle is also included.

Analysis pictures: -

Refer example of microscopic pictures for Part 1 as evaluated above.

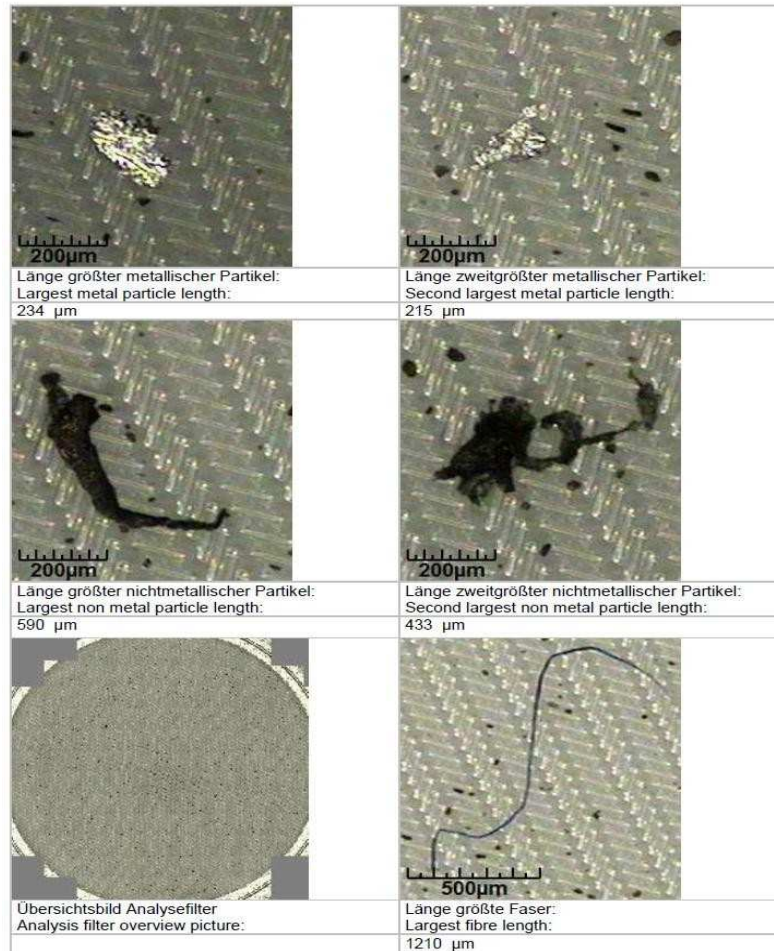


Fig.15: Particle evaluation pictures

VII. CONCLUSION

Here we see that the Technical Cleanliness Requirements are important attributes in terms of functional performance and reliability. "All automatic transmissions use precision manufactured electro-hydraulic components with very small clearances," says Lev Pekarsky, technical expert, contamination and filtration, Ford Motor Co. "Presence of even small - sized debris in those systems could cause degradation of transmission function such as shift engagement quality. That is the reason Ford and our competitors have been continuously improving cleanliness of all transmission components." Most of the components have narrow tolerances, high-precision fits and small microscopic openings. Tiny particle residues like in injectors, pumps and control units can cause malfunctions with serious consequences up to and including failure of the entire fuel-injection system. For components with requirements for technical cleanliness, specifications always prevail. These relate to production (clean-room environment, filter technology, special cleaning processes), testing (determination of decay behavior), packaging, handling, storage and transport, and are fundamentally related to increased cost.

References

[1], [2] & [3]: ZVEI_Guideline_Technical-Cleanliness-in-Electrical-Engineering_second-extended-edition_Version-2019

Fig. 09 & 10: ZVEI_Guideline_Technical-Cleanliness-in-Electrical-Engineering_second-extended-edition_Version-2019