



THE FOUNDATION OF A DEFECT TRACKING MATRIX AND CORRECTIVE MEASURES FOR DEFECT REDUCTION IN THE CRANKSHAFT FORGING INDUSTRY: A PATH TOWARD SUSTAINABLE MANUFACTURING PRACTICES & DRIVING INNOVATION IN QUALITY CONTROL

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ABSTRACT

Throughout the first decade of this century, the forging industry has experienced rapid expansion, with an increased demand for high-quality forged products requiring zero defects. This article lays the groundwork for limiting forging defects in the crankshaft forging industry sector. Success in this field demands a small rejection or scrap percentage, shortened lead times, and minimal waste in part production. Using a defect tracking matrix, this study identifies common defects such as underfills, laps, and cracks, which are primarily caused by improper material handling, inadequate die design, and insufficient process control. This defect tracking matrix, or cause effect matrix, has the ability to serve as a profound aid for both the design engineer and the producer for any and all aspects of forging and work piece topography that are destined for use in industry sectors that deal with crankshaft production. Key strategies to address these issues include optimizing die design, enhancing process monitoring, and improving operator training. The implementation of corrective measures led to a significant reduction in defects, with the final rejection rate decreasing from 4.57% to 1.93%. The most notable reductions were in defects like underfills, laps, and cracks. This approach not only improves product quality but also enhances overall efficiency in crankshaft manufacturing. The methodologies and strategies outlined can be broadly applied across the forging industry to achieve similar improvements in defect reduction and process performance.



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I. INTRODUCTION

The forging industry has expanded considerably during the course of this century. Most of the credit for this growth goes to the rapid emergence of more specialized technology, better materials, and heavier presses. Because of this, conflict among forging enterprises has heated up, and 'precise 1st time' products have become a top priority. Using forging systems quickly to make more assemblies has increased the demand for forgings that are free of flaws [1]. The method of metal forging is an effective one for the production of facilitating a robust structural parameter that meets compliance with the channel flow. Mass manufacturing of accurate components, including crankshafts and connecting rods, may be accomplished at a reduced cost. Forging deforms metals plastically using regionalized compressive forces. Manual or power hammers, presses, or other forging-specific machines apply these forces. Forging transforms a billet or ingot into the desired product [2]. When defects show up during the forging process, they need to be fixed quickly in order to meet both industry standards and the needs of local customers. To satisfy the requirements of the industrial evaluation criteria and the service standard, forging shortcomings are required to be resolved quickly.

During all stages of the forging process, this sector has a lot of problems, such as mis-location, laps, mismatch, un-filling, and seam cracks [3]. Getting closer to this goal could be helped by having a reliable model aid system that helps people avoid the most common kinds of mistakes. Because it's hard for a designer to find the best way to shape a product in as few steps as possible [4], this technology needs to be made. The metal handbook [5] specifies the following steps for forging procedures to be performed: trimming forging parts to remove flashes from the final forged part; hammering or pressing the hot billet in various imprint dies. The quality of a forged product depends on the billet's metal and configuration, die and material temperature, and the quantity and structure of intermediary dies.

Forged crankshafts are employed when load stress is applied, and mitigating measures are vital [6]. Within an internal combustion engine, there is a significant part called the crankshaft that rotates at a rapid speed [7]. The crankshaft is a crucial component of diesel engines and cars, and its complicated design includes cylinders that serve as bearings and arms that serve as crank webs, and it has a direct role in determining the engine's overall performance in terms of both power and efficiency [8]. It turns the reciprocating motion of the piston into rotary motion and then back into reciprocating motion with a simple mechanism. [9] The primary processes involved in producing the crankshaft in the forging industry are shown in (Figure 1). In this process, after heating, the billets are placed beneath the upper and lowest dies and pressed through into the desired form.

This happens in three steps: first, in the roller section, where the part is pre-shaped; second, in the blocker, where the part is rough-forged; and third, in the finisher die, where the finished shape is done. Based on analytical and practical designs as well as real experience, this article discusses the basic necessity of a defect tracking system. While defects may be found using simulations, their origin is still mostly unknown. Because of this, it would be helpful to have a system that lists problems, what makes them happen, and how to fix them. Forging defects and their likely sources are catalogued and organised into categories with accompanying guidance in the cause-effect matrix or by using a defect tracking system. This Defect-Tracking (Cause Effect) Matrix might be implemented into an intelligent system that directs the factory towards achieving "valid 1st time" output.

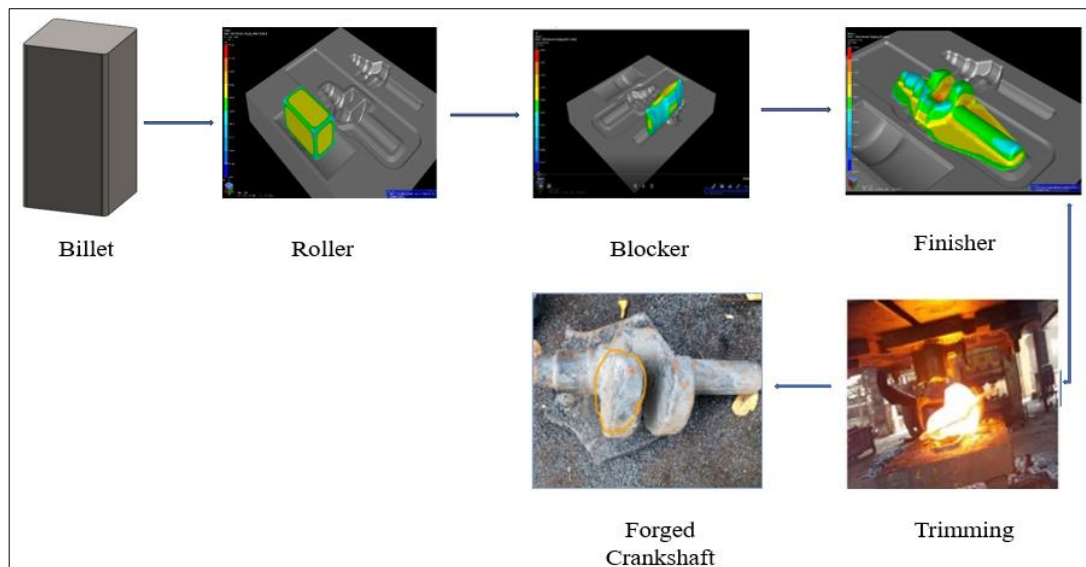


Figure 1: Vital crankshaft forging stages.
Source: Authors, (2026).

II. MATERIALS AND METHODS

II.1 MATERIALS FOR THE FORGED STEEL CRANKSHAFT

Materials for the crankshaft should be readily formed and produced, in addition to having sufficient strength, durability, and rigidity, as well as fatigue resistance power. Ingots of metal(steel) are formed into predetermined forms using specialized presses and other forging equipment to produce crank shafts. Because of advances in the technology used to make steel, it is now feasible to eliminate contaminants in the materials used to create crankshafts [10], [11-12]. Crankshafts are often produced from AISI 1040, AISI 1045, or a comparable kind of steel that is forged [13-14]. Medium-carbon steel alloys contain iron and 0.25-0.45 percent carbon, as well as chromium, nickel, manganese, silicon, cobalt, molybdenum, vanadium, and other elements. Manganese-molybdenum steel is an inexpensive forging steel used for petrol engine crankshafts; chromium-molybdenum steel for light commercial diesel engines; and nickel-chromium-molybdenum steel for heavy-duty diesel engines. Nickel-chrome-moly alloy AISI 4340 is a popular choice for high-performance crankshafts owing to its high strength, fatigue resistance, and ductility [15-17].

Crankshafts are typically made from various types of forged steel grades. Figure 2 illustrates a comparison of mechanical properties among different crankshaft materials. The development of new materials aims to reduce costs by utilizing enhanced micro-alloyed steels. These steels eliminate the need for heat treatment and offer improved material qualities, providing more options for product design. The assessed micro-alloy grades show potential cost savings compared to conventional materials such as tempered and quenched alloy steel (AISI 4140) or carbon steel (AISI 1050), with a reduction of 11% to 19%. In terms of performance, the fatigue strength of micro-alloy grades is generally equal to or higher than that of existing materials, while maintaining superior machinability. This makes micro-alloyed steel a common substitute for forged steel. By using 38MnVS6 or VANARD 925 air-cooled micro-alloyed steel instead of the typical AISI 4142 steel, the cost of the finished crankshaft can be reduced by 13% [18].

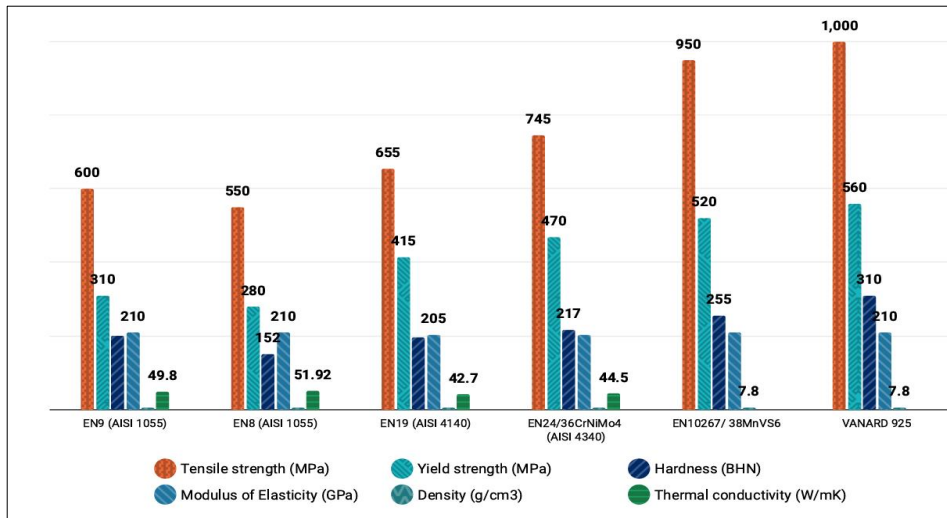


Figure 2: Comparative mechanical characteristics of particular crankshaft material. Source: Authors, (2026).

II.2 PRODUCTION METHOD OF THE FORGED STEEL CRANKSHAFT

One of the most important steps in the production process is forging. It results in a product with higher mechanical qualities and less waste. In comparison to other methods of production, such as casting, this is a significant advantage [19]. Forging is a traditional method of producing high-performance or elevated crankshafts; it involves heating a billet to the proper forge temperature, and afterwards repeatedly hammering or pressing it between pairs of dies at quite high pressure. The dynamic qualities of a crankshaft, such as its resistance to impact, as well as cyclic loads, are improved during the forging process. The methodical procedure for producing a crankshaft [20] is shown in (Figure 3). Crankshafts that are forged are typically made by primarily using the processes of hot forging in combination with machining in order to put together the final product. [18-20] Monitoring the geometric diversity that results from shifts in temperature may be done in a number of different ways [21]. As the billet moves through the top and lower die configurations, it is purposefully distorted so that the ultimate product will be as good as it can possibly be [5], [22].

II.3 DEFECTS IN THE PRODUCTION OF CRANKSHAFTS DURING THE FORGING PROCESS

Operators and engineers may discover defects at any point after or during an activity or process and must speculate as to when, how, and why the defect emerges. At some point, researchers might require certain sources of evidence in order to predict the cause of the problem, the kind of part, the position of the defect on the component or part, the severity of the defect, etc. [23-24]. A framework of the defect diagnosis process is shown in (Figure 4) [25-26]. Forging defects are often the result of defective ingots, inaccurate heating, bad forging circumstances, inappropriate forging procedures, and unequal chilling of the stock upon forging [27]. In every forging operation, the manufacturer may run across a wide range of defects throughout the production process.

The product is often pulled off the market as a consequence of these problems. The defects in forged metallic components may be discovered with the use of image recognition, and the authors speculate that this method might be used to reduce stresses and fatigue throughout a physical assessment [28]. A cost-effective forged product free of forging defects is ensured by a well-designed shape and respect to the normal flow. Also among these factors are full cavity filling, good material properties, little die wear, longer die life, and good material properties [29]. To achieve an ideal design with a focus on stress distribution [1], forging defects must be eliminated, and metallic grain flow must be improved throughout the forging process.

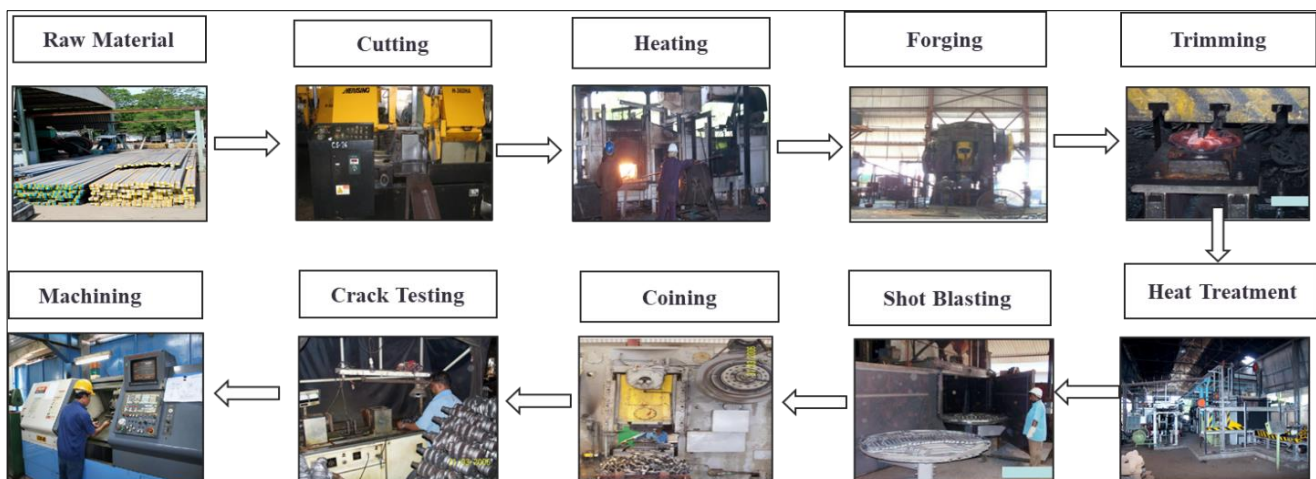


Figure 3: The Steps Involved in the Production of a Crankshaft. Source: [19].

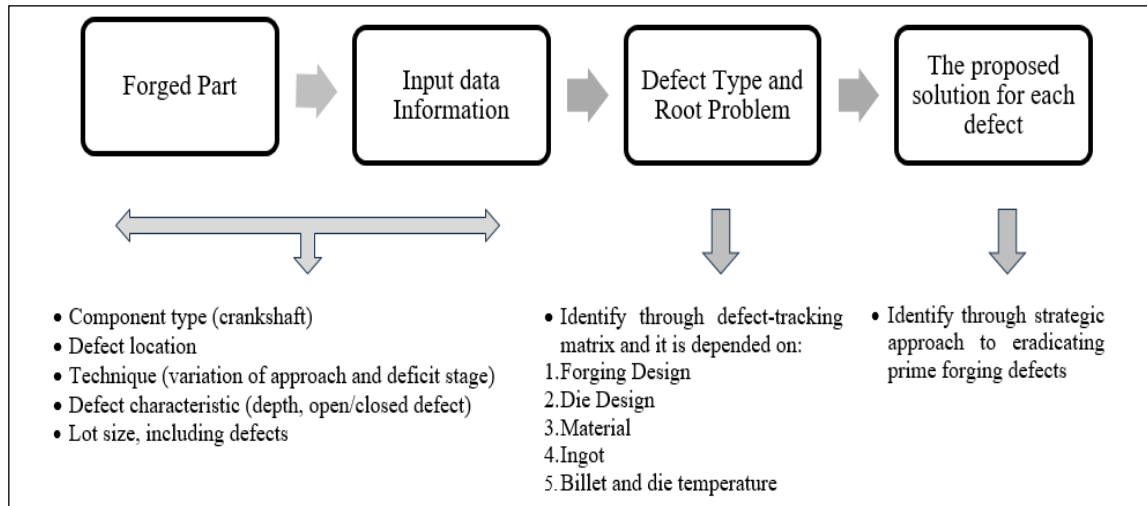


Figure 4: The basic forging defect. diagnosis process.

Source: [25-26]

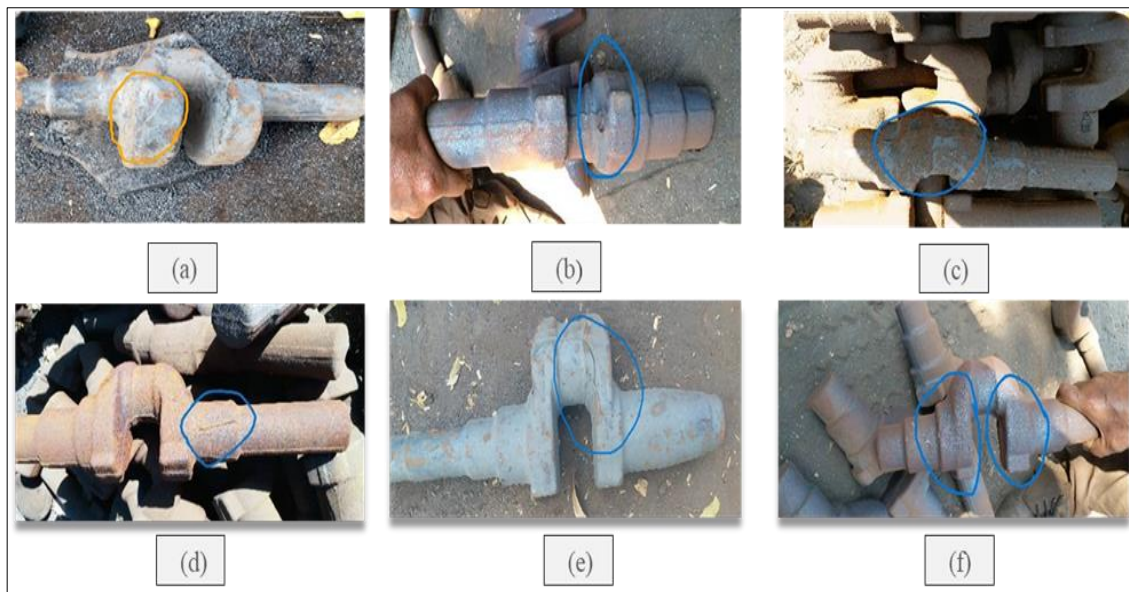


Figure 5: Forging Defects in Crankshafts(a) Unfills at counterbalance weight (b) lap at crankpin (c) Mismatch at side of journal (d) Mislocation on bearing area (e) Crack (f) Scale Pitting at on web and on bearing area.

Source: [19].

When it comes to forged components, the most typical cause of rejection or failure is the appearance of cracks on the inside [30]. The best strategy for decreasing forging defects was determined using the AHP-TOPSIS Method. The under-fill error is a significant issue in the field of investigation since it happens at such a high incidence in this sector [31]. Using the defect matrix, the first step entails the categorization of possible offenders into the following six groups: cracks, surface inadequacies, owing to shear flaws, folds, overlap defects, and form and structural defects. The second step classifies potential causes into different categories by using a tool called the defect matrix. This tool illustrates how different defects interact with each other as well as the factors that contribute to them [32]. The Deform-3d software application [33] can reliably forecast defects like underfill, residual stresses, and folds during fast heating. Defects are common in the crankshaft forging sector (Figures 5), with reflecting practices of recurrence [19].

II.4 METHODS AND STRATEGIES USED TO REDUCE REJECTION RATE IN CRANKSHAFT FORGING

This research article centers on crankshafts manufactured through hot forging, tailored for use in single-cylinder engines produced by Forge and Forge Pvt. Ltd. Rajkot. Industry faces an Approx. 5% rejection rate. Table 1 highlights production metrics over two consecutive 12-month periods: before corrective measures (2019-2020) and after (2020-2021) for the forging of single-cylinder crankshafts. Table 2 details defect types before and after implementing corrective measures. Table 3 outlines specific measures for preventing and addressing catastrophic major forging defects encountered in crankshaft production.

Table 1: Monthly Production Data and Defect Analysis Before and After Corrective Measures.

Metrics	Before Corrective Measures (12 Months)	After Corrective Measures (12 Months)
Total Production	120,284	113,112
Parts Accepted	114,783	110,927
Ultimate Rejection	5501	2185
Percentage of Final Rejection	4.57%	1.93%

Source: Authors, (2026).

Table 2: Defect Analysis and Contribution of each defect.

Defect Type	Counts, Before Corrective Measures (12 Months)	Counts, After Corrective Measures (12 Months)
Unfilling	3594	1565
Lap	716	188
Mislocation	521	229
Mismatch	355	122
Crack	73	44
Burnt	47	7
Scale Pit	177	30
Dent	11	0
Oversize	7	0
Total	5501	2185

Source: Authors, (2026).

Table 3: Preventing and correcting catastrophic forging defects in crankshafts.

Defect grading	Main forging defects	Protective and restorative measures
UF	Unfilling	Embed the blocker mode of operation of the dies by highlighting the areas that are not filled with the appropriate material.
		It is possible that the counterbalance masses for forged crankshaft may be revised or omitted altogether.
		Ensure that the employee receives the time and care they need in order to reduce the likelihood of mistakes occurring.
		Choose the kind of lubricant that is most suited for the specific die you are using and the corresponding raw material benchmark really has to be implemented as soon as possible.
		The integrity of the billet for the length of time provided may be easily confirmed by doing a physical check at many places more than thrice.
		Check the design of the roller and raise the depth by two to three millimetres in order to combat the underfilling effect.
		Set the burner towards the ideal temperature in order to heat it up enough.
LA	Overlap	To reduce the likelihood of incidents, provide a thorough training programme.
		In order to ensure consistency in quality, the right raw - materials norm must be implemented.
		Using a rubbing motion to grind the die's chamfered edges is advised.
		In order to fulfil the specifications of the design, the deformity of the blocker dies had to be eliminated.
		Before the user starts, the user should first preform the shape at the exact angle.

Source: Authors, (2026).

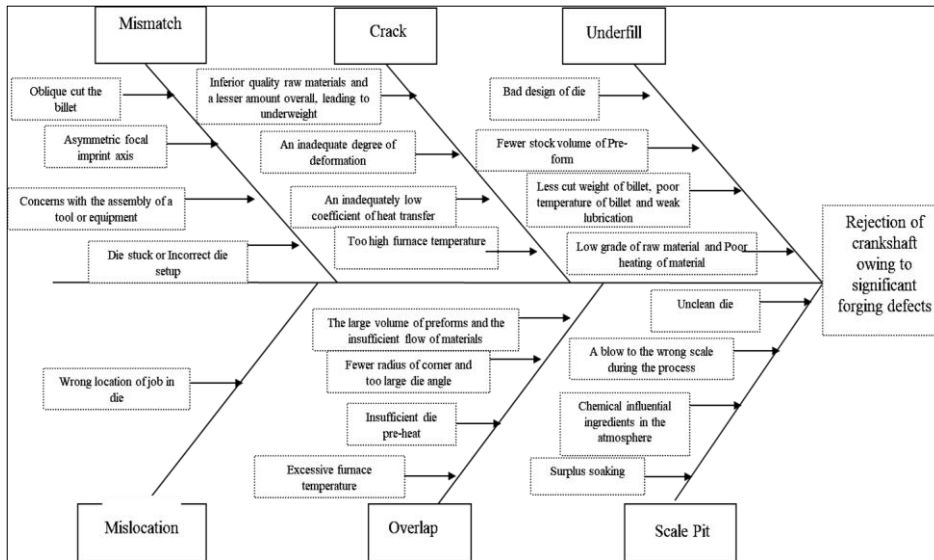


Figure 6: Cause effect of crankshaft rejection diagram for major defects of forging industry. Source: Authors, (2026).

The cause-effect diagram (Figure 6) for significant defects in the forging sector, particularly with crankshaft rejections, depicts the main causes that contribute to incidences of rejection. The image above classifies significant defects and links their origins to certain root causes. By categorizing these components into distinct groups such as materials, processes, equipment, and human factors, it aids in the identification of possible causes of defects and provides direction for improvement initiatives. This tool is very beneficial for systematically assessing and correcting quality concerns in the forging process, with the goal of reducing rejection rates and improving overall product quality. Pareto analysis is a method used to discover and rank the most important factors that contribute to a challenge. Figure 7 illustrates the distribution of forging defects and percentages of rejection for single cylinder forged crankshafts in their original state, prior to the implementation of any remedial actions.

The defects are often classified according to their frequency or the extent to which may affect rejection rates. The highest bars in the Pareto chart represent the problems that occur most often or have the greatest severity. These bars suggest the areas where efforts should be concentrated in order to minimize rejection rates and enhance overall quality, prior to implementing remedial measures. The investigation reveals that over 80% of rejection difficulties stem from 20% of the detected faults. The Pareto principle implies that a vast majority of the rejections may be ascribed to a limited number of distinct fault categories. According to this research, the main reasons for rejecting single cylinder crankshafts forging are under-fills and overlaps, which account for over 75% of the rejections. This information is shown in Figure 7.

Figure 8 illustrates the outcomes of Pareto analysis after the implementation of remedial actions to resolve the highlighted defects from Figure 7. The image displays a revised proportion of defects and rates of rejection, demonstrating the influence of the implemented remedial measures. Optimally, after the implementation of measures such as process optimizations, quality control advancements, training initiatives, or equipment enhancements, the tallest bars in Figure 8 ought to indicate decreased frequencies or severities of faults. This indicates a positive advancement in reducing the number of rejected products and attaining superior product quality in the forging operation. According to the investigation, the main reasons for rejecting single cylinder crankshafts forging are under-fills and overlaps, which account for over 80% of the rejections. This information is shown in Figure 8.

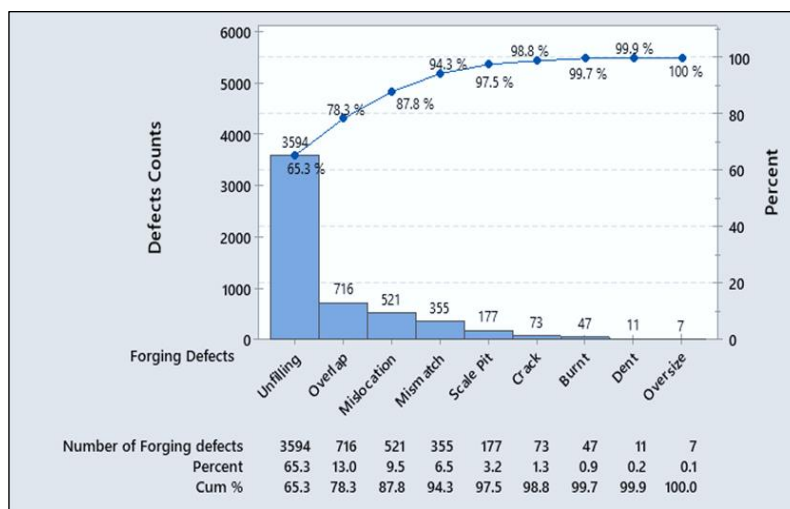


Figure 7: Pareto Diagram of Forging Defects counts and Rejection Rates for Forged Crankshafts (Before Implementation of Corrective Measures) Source: Authors, (2026).

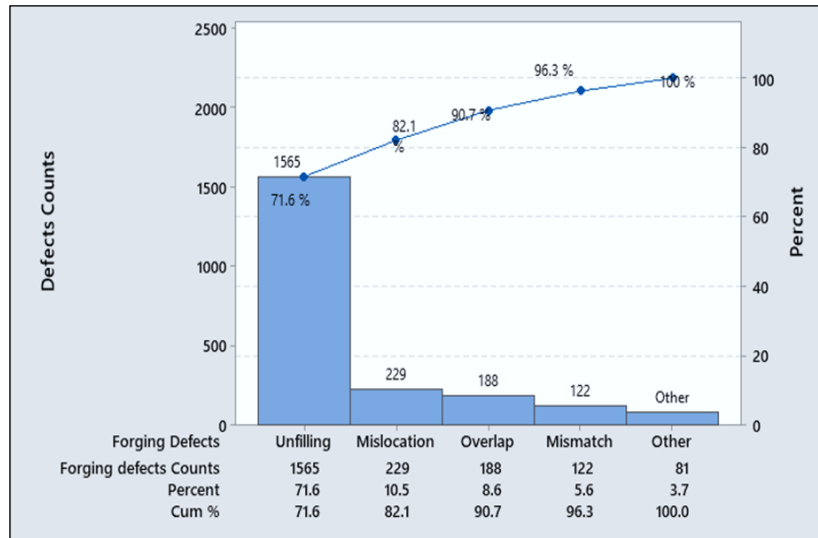


Figure 8: Pareto Diagram of Forging Defects counts and Rejection Rates for Forged Crankshafts (After Implementation of Corrective Measures).
Source: Authors, (2026).

III. RESULT AND DISCUSSIONS

III.1 DEFECT – TRACKING MATRIX FOR CRANKSHAFT FORGING INDUSTRY

An author [32] came up with the idea of a defect matrix, which is a tool that can be used to tie a forging defect first to factors that have the potential to cause it. A cause-effect diagram is a visualization tool that may be used to logically arrange the potential causes of a certain issue or repercussion by visually portraying those potential causes in greater detail. It can also reveal causal links between different hypotheses. A fishbone diagram, or an Ishikawa diagram, is one of the most common names for this form. [34-36] Figure 11 is a cause-and-effect diagram that illustrates the massive defects that led to the crankshaft rejection during the manufacturing process. The design and arrangement of a defect-tracking matrix is shown in (Figure 9-11), which is relevant to the crankshaft forging industrial sector.

The Defect-Tracking Matrix has twenty-two flaws arranged vertically and upwards of five groups (Table 4) of probable causes for the defects arranged horizontally. The major groups are presented just to make the matrix simple to read; nevertheless, in (Figure 9-11), a portion of the whole Defect-Tracking Matrix or Cause Effect Matrix is shown; this section contains the characterization of the self-styled foundation as like specialist assistance for forging. In (Figure 9-11) the symbol "*" shows that there is a link between both the main causes or possible factors contributing to rejections and forging defects. (Figure 9-11) depicts the second defect tracking matrix for the crankshaft forging sector in accordance with the operator and materials factors. (Figure 9-11) depicts the first defect tracking matrix, or cause and effect matrix, for the crankshaft forging enterprise in terms of tool and machine factors.

(Figure 9-11) depicts the second defect tracking matrix for the crankshaft forging sector in accordance with the methods and environmental factors. The marks in the defect-tracking-matrix are dependent on the process that is currently being used, which is the reason why a cause-effect matrix is required to be developed for each and every type of forging process. A task of this kind will need much too much time and will be very challenging to summarise. Because of this, the processes need to be separated into their respective primary groups according to criteria such as the geometry of the tool and workpiece or the operation that is more frequent. For each Defect-Tracking-Matrix, the marks that indicate the link between the defect and what might cause it will produce an agenda that is unique to the process that is now being carried out.

Table 4: Five groups’ Parameters for possible causes laid out horizontally.

Vertically Forging Defects	Horizontally Probable causes				
	Main Group 1 Process	Main Group 2 Environmental	Main Group 3 Tools	Main Group 4 Materials	Main Group 5 Operators
Example Laps	Sub group 1 Sub group 2	Sub group 1 Sub group 2	Sub group 1 Sub group 2	Sub group 1 Sub group 2	Sub group 1 Sub group 2
	Each Sub group Cause 1 Cause 2	Each Sub group Cause 1 Cause 2	Each Sub group Cause 1 Cause 2	Each Sub group Cause 1 Cause 2	Each Sub group Cause 1 Cause 2

Source: Authors, (2026).

III.2 EFFECTIVENESS OF CORRECTIVE MEASURES IN REDUCING DEFECTS AND IMPROVING QUALITY

Based on the data analysis presented in Tables 1, 2, and insights from Table 3 regarding corrective measures, significant improvements in production quality and defect reduction are evident following the implementation of strategies at Forge and Forge Pvt. Ltd. Rajkot. Over a 12-month period, total production slightly decreased from 120,284 to 113,112 parts and the acceptance rate improved from 114,783 to 110,927 parts. Notably, ultimate rejections dropped from 5,501 to 2,185 parts, with final rejection rates decreasing from 4.57% to 1.93%. Specific defect reductions include unfills (3,594 to 1,565 occurrences) and lap defects (716 to 188 instances). These improvements reflect effective strategies like die design optimization, process controls, and operator training, enhancing quality, customer satisfaction, and operational efficiency in the competitive forging industry.

Defect Tracking Matrix for Crankshaft Forging Industry sectors (Cause Effect Matrix)			Possible Factors Contributing to Rejections																	
			Parameters for Tool/Workpiece Material										Parameters for Operators							
			Seam Crack(Input Material Defect) of Billet	Too Low Heat Transfer Coefficient	Too High Thermal Expansion Coefficient	Inclusions	Underweight	Discontinuities in Microstructure	Too Soft Die Material	Too High Elastic Material	Poor Raw Material Grade	Too Large Grains in the Material	Lack of Training	Less Skilled Worker	Improper Placement of Stock on Die	Improper Die setting	Surplus Material escapes to side	Improper Scale Blowing in Operation	Careless Handling of Jobs	Uncleaned Dies (To Soil with dirt or impurities)
Sr.No.	Forging Defect	Code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Mismatch	MM								*			*	*		*		*		
2	Unfilling	UF	*						*		*		*	*		*		*		*
3	Closure	CL																		*
4	Oversize	OS							*											
5	Undersize	US			*															
6	Mislocation	ML																		
7	Overlap	LA	*										*	*				*		*
8	Chopping	CH														*				
9	Overheating	OH																		
10	Dent Mark	DM													*					*
11	Punch Mark	PM																		
12	Bend	WA																		
13	Twist	TW																		
14	Surface Crack	SC	*	*	*			*	*		*									*
15	Eccentricity	EC								*										
16	Scale Pit	SP				*				*								*		*
17	Excess Burr	EB							*		*			*				*		*
18	Excess Shear	ES																		
19	Poor Mechanical Properties	MP								*										
20	Poor Formability	FL					*													
21	Monogram	UM																		
22	Heat Number	UH																		

Figure 9: Defect Tracking Matrix of Tool Materials and Employee Constraints for the Crankshaft Forging Sector. Source: Authors, (2026).

Defect Tracking Matrix for Crankshaft Forging Industry sectors (Cause Effect Matrix)			Possible Factors Contributing to Rejections																									
			Parameters for Machines/Tools																			Press			Surface			
			Preform			Design & Geometry																						
Sr.No.	Forging Defect	Code	Less Stock Volume of Preform	Too Large Volume of Preform	Improper Preform Geometry	Eccentric Centre Line of Impression	Obliquely Cut Billet	Narrow Instable Sections	Poor Die Design	Insufficient Die Preheat	Misplacement between Dies	Blocker Mismatch	Inappropriate and Poor Geometry of Die	Die Locked	Wrong Location of part in tool	Less corner Radius	Too Large Die Angle	Sharp Edges of Tool	Tool Assemblings Error	Incorrect Positioning of Flash	Inadequate Press Force ,Energy and/or Power	Improper Capacity	Due to Die Land Worn Out	Punch Worn Out	Surface Wornout of Die	Tool Hardness	Too Rough Surface	
1	Mismatch	MM				*	*			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	Unfilling	UF	*		*				*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	Closure	CL							*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
4	Oversize	OS																										
5	Undersize	US																										
6	Mislocation	ML													*													
7	Overlap	LA		*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
8	Chopping	CH									*																	
9	Overheating	OH																										
10	Dent Mark	DM																										
11	Punch Mark	PM																					*					
12	Bend	WA																										
13	Twist	TW							*																			
14	Surface Crack	SC				*										*												
15	Eccentricity	EC				*													*									
16	Scale Pit	SP																										
17	Excess Burr	EB		*	*										*						*						*	
18	Excess Shear	ES													*	*			*		*							
19	Poor Mechanical Properties	MP																										
20	Poor Formability	FL																										
21	Monogram	UM																										
22	Heat Number	UH																										

Figure 10: Defect Tracking Matrix of Machine/Tool Constraints for the Crankshaft Forging Sector. Source: Authors, (2026).

Defect Tracking Matrix for Crankshaft Forging Industry sectors (Cause Effect Matrix)				Possible Factors Contributing to Rejections																					
				Parameters of Process																					
				Thermic			Due To Flow				Geometric				Local			Friction			Parameters for Environmental				
				The temperature of the furnace is too high	Less Temperature of Billet	Heating at a very rapid rate	Poor Heating of Material	Improper Material Flow	Insufficient Number of Blews	Low Cut Weight of Billet	Improper Deformation	Heterogeneous Deformation	Incorrect Position of Billet	Too protruded a stroke	Distortion along the Length of Part	Distortion Across the Width of Part	Improper Arrangement After Cutting	Monogram not Visible	Heat Lot not Visible	Too High Friction	Low grade Lubricant	Improper Lubrication	The Presence of Chemically Active Contaminants in the Environment	Excess Soaking	Surplus Air in the Surrounding Environment
Sr.No.	Forging Defect	Code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
1	Mismatch	MM									*														
2	Unfilling	UF	*	*			*	*	*		*	*								*	*				
3	Closure	CL	*																						
4	Oversize	OS																							
5	Undersize	US																							
6	Mislocation	ML																							
7	Overlap	LA	*	*			*					*	*							*	*	*			
8	Chopping	CH																							
9	Overheating	OH	*																		*				
10	Dent Mark	DM																							
11	Punch Mark	PM																							
12	Bend	WA												*		*									
13	Twist	TW													*										
14	Surface Crack	SC	*		*	*			*		*	*												*	
15	Eccentricity	EC									*														
16	Scale Pit	SP	*																		*	*	*	*	*
17	Excess Burr	EB																							
18	Excess Shear	ES											*						*						
19	Poor Mechanical Properties	MP																							
20	Poor Formability	FL																							*
21	Monogram	UM															*								
22	Heat Number	UH															*								

Figure 11: Defect Tracking Matrix of Process and Environmental Constraints for the Crankshaft Forging Sector. Source: Authors, (2026).

IV. CONCLUSIONS

1. The Defect-Tracking-Matrix or Cause-Effect Matrix may provide guidance to the manufacturing and design specialists, allowing them to resolve a problem with the product and create a robust component. The foundation of a Defect-Tracking-Matrix was created for the economic advantage of the crankshaft forging industrial sectors to correct forging defects. The developer may get direction from the cause- effect matrix using any of two approaches. The first approach is referred to as the "detection mode," and it's used when the developer wants to figure out why a certain defect is present in the product and exactly how to get rid of it. Because the Defect-Tacking Matrix is being used horizontally throughout this context, it is feasible, for a given defect, to acquire data on which variables might produce the defect as well as a potential strategy to avoid it. This is because the defect-tracking-matrix is used in this context.

The 'advising solutions mode' of the Cause Effect Matrix is another use of its capabilities. With the 'advising solutions mode' method, the Defect-Tracking-Matrix is used in a vertical orientation, providing information on the defect possibility associated with each operating factor. It presents the theoretical foundation for a method to reduce the overall quantity of defects in a forged product. The Defect-Tracking - Matrix is a database or catalogue of defects that may be generated for a wide range of forging methods and workpiece shapes to serve as a helpful tool for the design process. It is possible for a design engineer to employ a Defect-Tracking-Matrix in practice, although the factors of that procedure may not match those given here. Because of this, more tests using numerical or parametric methods may be needed to back up the Defect-Tracking-Matrix results.

2. The implementation of targeted corrective measures at Forge and Forge Pvt. Ltd. Rajkot effectively reduced total rejection rates and specific major forging defects, significantly enhancing production quality and operational efficiency.

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