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A Review of Various Defects in PCB

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Abstract
Printed Circuit Boards (PCBs) are the building blocks for all electronic products. Fabrication of a PCB involves various mechanical and chemical processes. As obtaining accuracy in the mechanical and chemical processes is very difficult, various defects/faults are formed during PCBs fabrication. These fabrication defects lead to performance degradation of electronic products. In this review, we describe various defects present in PCBs under the Through hole and SMD categories. To understand the frequency of occurrence and reason for the occurrence of defects in both manual and machine, PCB fabrication data was collected and analysed from April 2017 to July 2020 as a part of industry collaboration.

Keywords Short faults · Open faults · Component faults · Soldering defects · PCB defects

1 Introduction

The performance and the life of electronic products are dependent on the quality of PCB boards integrated into the product. During the production cycle, the product goes through testing at various levels- component level, PCB level, Pre-package and System level. If faults are identified at the early stages (i.e., before reaching the customer) the cost of manufacturing can be kept low, as the product can be repaired or discarded before packaging. Otherwise, it will affect the reputation of the organization [1]. Small defect formation during fabrication causes large damage to the product which leads to recall of the product. Hence it is necessary to identify the defect during the manufacturing cycle itself. The first step is to understand various defects present in PCB. In this review paper, we present an overview of various defects present in the PCB.

Survey paper [2], covers a range of defects such as breaks, shorts, missing conductor, missing component, etc. and covers around 12 types of defects and gives a procedure for inspection of PCB. In [3], authors detected defects such as bridge, empty, excess solder, appearance hole, appearance less, appearance, etc. Whereas in the paper [4]various solder defects such as cold solder, solder insufficient, component shifting, wrong component, tombstone, etc. are detected. The various SMT defects covered in reference papers [5, 6] are component shift, component missing, component value erase, upside mount, pin bend, tomb stoning, component damage, component polarity, breakout, pinhole, open, under etch, mouse bite, missing conductor, spur, short, spurious copper, excessive short, missing hole, etc.

In this review paper, we cover a wide range of defects (34 defects), classified according to various categories for easy understanding. In this paper, we have looked into the defects which occur during the PCB board assembling process in both Through hole technology and SMD technology along with their acceptance and not acceptance criteria. The Bare PCB defects such as Plating voids, slivers, PCB Warp Edge, missing solder mask between pads insufficient copper to edges clearances, acid traps, starved thermal, and electromagnetic issues are tested in the PCB fabricator end and Test certified PCB's are received to collaborative company. At the PCB's incoming inspections stage, company conducts 100 % visual inspection and checks that if it is ok then pass it or else Reject it. In addition to the above defects, the following defects also were tested and certified by PCB fabricator.

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1. Surface solderability
2. Hole solderability
3. Bow & Twist
4. Conductor pattern
5. Annular ring
6. Solder mask cure Adhesion
7. Legend Printing
8. Circuit continuity
9. Surface Finish
10. Copper exposures

In this manuscript, we consider only studying compound mounted PCB defects which are important for the performance of overall PCBs and cannot be tested at the bare PCB fabrication stage. An overview of the defects classification tree diagram is given in Fig. 1.

Through hole PCB is one where the PCB board is full of holes and components are inserted into the holes and then soldered. SMD is one where the circuit is designed to be mounted onto the PCB. Information about the various defects is collected from Industry visits, discussions and meetings with the industry partner as a part of Industry-academia collaboration. Defects have been classified based on data obtained from one industry over multiple design PCB fabrication over 4 years (April 2017 to July 2020) and classification is based on Pictorial Interpretive documents of IPC 610D standards [7]. This standard describes what are the possible defects, the identification of defects, and the reason for the occurrence. Almost all same types of defects are found in other industries as we observed from some of the reference papers.

The paper is organised as follows. In Sect. 2, we discuss various types of defects occurring in PCB manufacturing. In Sect. 3, we compare these defects and conclude the paper in Sect. 4.

2 Different Types of Defects

The various defects present on PCB can be broadly classified into soldering defects and non-soldering defects. The PCB soldering defects have been classified into five types - Bridge, Excess solder, open, Appearance Hole, Appearance less, and Excess material [8]. The non-soldering defects can be sub classified into wiring track faults, Wrong Polarity, Missing Components, and Misaligned components [9, 10]. Below we describe the various types of defects.

2.1 Soldering Defects

An established solder joint provides mechanical support and electrical support (electrical interconnection) to the components and PCB. A good solder joint should provide the characteristics shown in Table 1.

In Bridge type fault we have excess solder at the port and they might short two different ports. It can be caused due to excessive solder paste slump, unsuitable reflow profile,

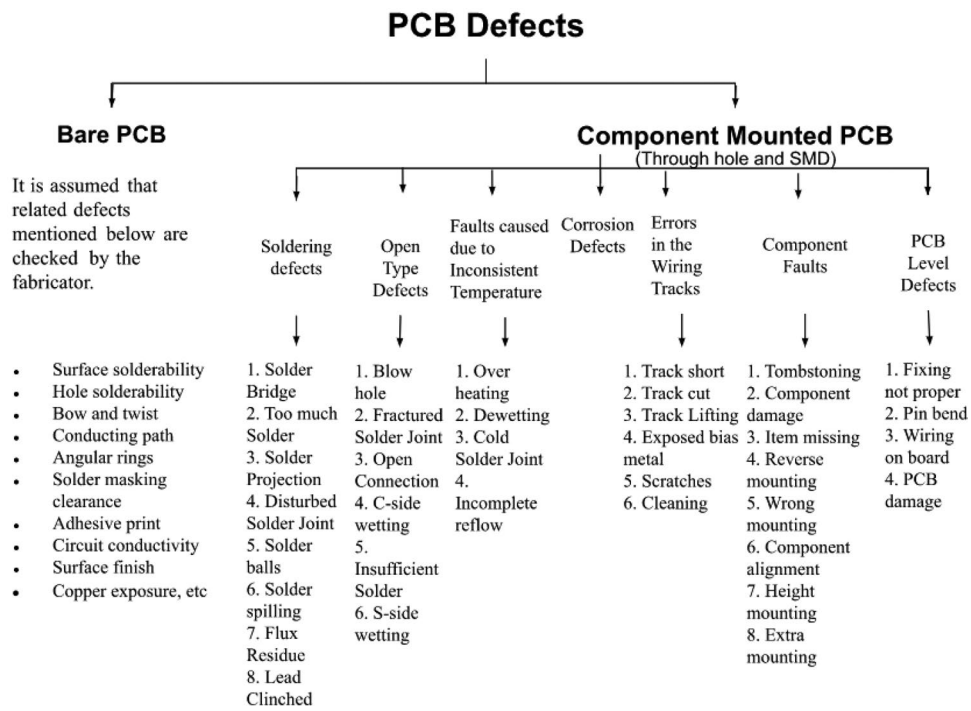
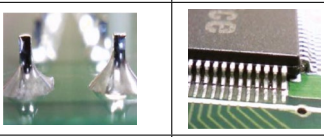
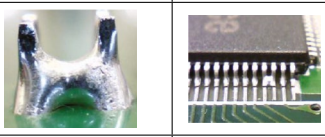
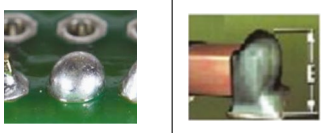
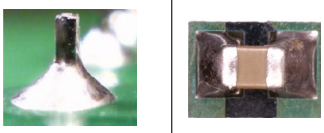
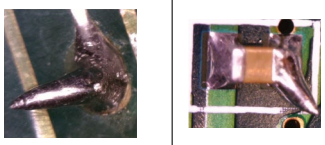
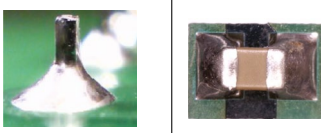
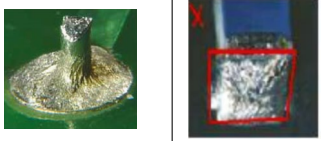
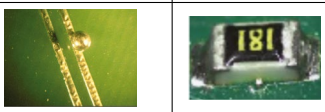
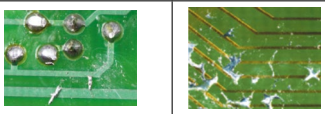
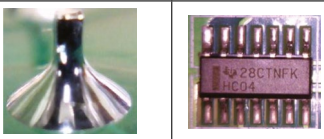
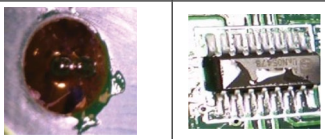
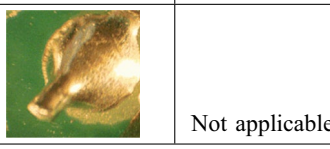


Fig. 1 Defects classification tree

Table 1 Soldering defects

Defect Type	Accepted		Not Accepted	
	Through Hole	SMD	Through Hole	SMD
Solder Bridge				
Too much solder				
Solder Projection				
Disturbed Solder Joint				
Solder Balls				
Solder Spilling				
Flux Residue				
Lead Clinched		Not applicable		Not applicable

relatively big soldering pads compared to the gap between pads, too much solder on the pads due to incorrect stencil specification, not active solder paste, a bad seal between the stencil and the board during printing, mismatch between the stencil and PCB, poor component placement or poor component leg to PCB pad size relationship. Bridging faults can be classified into two categories, namely, strong bridging faults and weak bridging faults. A strong bridging fault is one in which excess solder leads to joining of unwanted pins. Weak bridging fault is where there is an excess solder which will lead to bridging fault in long run. A weak bridging faults lead to reliability issues and reduce the life of the board. So they have to be detected and such PCB boards have to be rejected. Various types of weak bridging faults include solder projection at the pin which might potentially lead to either short with a track or neighboring pin, too much solder, disturbed solder joint - where the connection is not smooth, solder balls, solder spilling, flux residue, track short, and clinched lead. In case of a Solder Bridge defect, the soldering should be smooth and no excess solder should be making unwarranted joints. It is not acceptable if the solder makes unwanted connections with other lead (or) Solders leading to bridged connections to adjacent joints. In the case of Too much solder defect, Concave shape of solder joint is desirable, thus it will give structural integrity and make sure bridging faults do not form. Otherwise, it is not possible to

ensure inside solder joint connectivity which is not desirable. In the case of a Solder projection defect, the soldering should be smooth without any excess solder material which is desirable. Undesirable projection of lead causes bridging faults in long run or will lead to EMI faults. Excess solder on soldering iron tip, low soldering temperature, improper soldering method, and Solder wire composition are some of the causes of solder projection defect. It is desirable to have a smooth solder joint and there should be no movement of components during soldering. A disturbed solder joint is characterized by the appearance of stress lines due to motion between the metals being joined while the molten solder was solidifying. Solder balls are considered a contaminant and are an indication of improper process control (inadequate preheat) and/or the use of outdated solder/flux. Also, in the case of solder spilling defect (solder splatter), that is caused by moisture contamination which is an indicator of poor process control. Flux is used for creating good metallurgic bonds during soldering. If the flux residue is there on the PCB it would lead to electronic failure and current leakage which is not desirable. In the case of a Lead clinched defect, conductor/lead ends may be clinched, with the clinched length at least $\frac{1}{2}$ the largest solder pad dimension, bent in the direction of the longest pad dimensions. Clinched leads shall not violate minimum electrical spacing requirements which are desirable. Whereas it is not desirable if component leads clinched toward an electrically uncommon conductor [11–13].

The short faults in PCB might occur because of one of these reasons: excessive solder paste slump, reflow profile not suitable i.e initial ramp rates too steep, soldering pads too big relative to gap between pads, too much solder on the pads due to incorrect stencil specification, solder paste not active enough, a bad seal between the stencil and the board during printing and mismatch between the stencil and PCB, poor component placement or poor component leg to PCB pad size relationship.

2.2 Open Type Defects

Open fault is caused due to missing solder. Open faults are further classified into strong open faults and weak open faults. In a strong open fault complete connection will be missing. In weak open fault, soldering will be partial and in overtime, they become open faults. The various types of weak and strong open faults are shown in Table 2.

Houdek and Design [9] and [12] In the case of Blow hole defect (large hole formed in molten solder), the solder joint should be smooth and shiny. If the hole exists inside the joint, then quality cannot be ensured. It is caused when gases burst through the solder during solidification or usage of improper soldering iron tip. A fractured solder joint indicates the evidence of cracking that results from movement between the conductor and termination, after solidification of the solder. It occurs due to improper handling or when the joint has been subjected to extreme mechanical stress. Open connection defect is not acceptable as the lack of proper connection will lead to unreliable electrical connection. Possible reasons for open connection defects are: Person negligence or overlook, bad solder ability of the component soldering surfaces due to oxide or contamination, solder paste not active enough, poor reflow profile which does not allow surfaces to come up to reflow temperature, not enough paste present or in case of Small Outline Integrated Circuits (SOICs), Plastic Leaded Chip Carriers (PLCCs) and Quad Flat Packages (QFPs) often coplanarity is the problem.

In the case of C-side (Component side) wetting defects, it is desirable to have the solder fill should be more than 75% of the contact for electrical reliability. If the fill is less than $< 75\%$ of vertical solder fill it would lead to electrical faults over the life of the PCB. Possible reasons for its causes are improper soldering method, improper soldering time, and low soldering temperature. In the case of S-side (Solder side) wetting defect, the solder joint should be smooth and it has to encompass the contact. If the solder connection is less than $< 270^{o}$C, then it is not acceptable as it might lead to reliability issues. These defects are caused due to excess solder on the soldering iron tip, low soldering temperature, solder wire composition, or improper method of soldering [9].

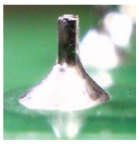
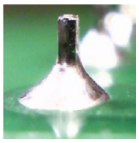
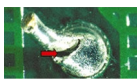
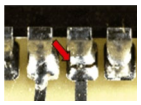
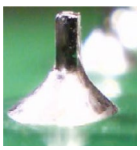
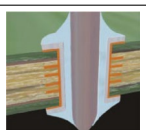
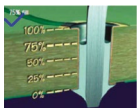
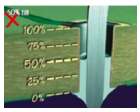
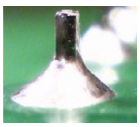
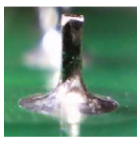
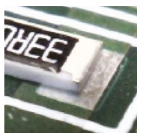
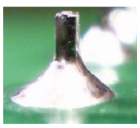
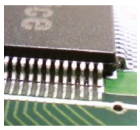
An Insufficient Solder defect is characterized by incomplete coverage of one/more of the metal surfaces being joined or by incomplete solder fillets. This is not acceptable as partial contact will lead to electrical faults over a period. This defect occurs when solder paste is not active enough, solder pads or component leads are not solderable or contaminated, the solder powder is oxidized or is too fine for the application and the reflow profile is not suitable i.e preheat too high/too long or peak too high.

2.3 Faults Caused Due to Inconsistent Temperature

The temperature requirements of the solder and the contact should be properly maintained otherwise will lead to faults. Temperature faults might lead to PCB delamination, solder pad damages, reliability issues over time, etc. Some of the faults due to inconsistent temperature are shown in Table 3.

Overheating causes De-wetting, lumps, and dull, crystalline-like structures (looks like sand has been thrown into the joint). Besides varying station temperature, other reasons for overheating could be component mishandling, repeated reworking/re soldering or over soldering time. De-wetting defect is a condition whereby a surface has

Table 2 Open type defects

Defect Type	Accepted		Not Accepted	
	Through Hole	SMD	Through Hole	SMD
Blow Hole				
Fractured Solder Joint				
Open Connection				
C-side Wetting				Not applicable
Insufficient Solder				
S-side wetting				

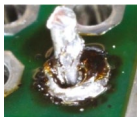
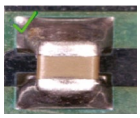
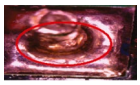
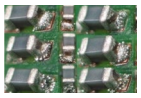
contacted molten solder, but the solder has not adhered to the entire surface and the basis metal remains exposed which is not desirable. It can be caused by any of the following reasons: lead conditions and contamination, insufficient soldering temperature, excess amount of heat, or insufficient flux content. A cold solder joint is an indicator of incorrect process control (i.e.: inadequate heat or insufficient soldering time. It causes Poor wetting, and stretch marks between the pad and lead). In the case of Incomplete Reflow, solder is not fully molten, and the joint is not formed. Solder paste balls are visible, which is not desirable. Inconsistent temperature is an indicator of improper process control/ thermal design where we observe browning/darkening of the laminate occurs excess heat. Hence we need to avoid excess heat [9]. The critical requirements for good soldering are:

The temperature has to be set to 320 °C - 350 °C for lead-free and 270 °C-300 °C for lead-based soldering

2.4 Corrosion Defects

The solder joints have to be shiny, as per the ITC standard, to meet their targets. The IPC standard pictorially specifies that for a good quality solder, the target soldering joint should be shiny, conical shape and has a smooth finish. Shiny in the sense that it should not have any particles. If we do not clean the solder tip, then solder flux will accumulate on it, and this causes the soldering joint will not to be shiny and the quality also degrades. Also, due to corrosion, the resistivity of the joint will change and overtime the reliability of the joint will decrease and lead to joint failure. Corrosion defects are caused due to improper storage, use of expired components, or ferried conditions. Corrosion of component lead will create bad contact with the solder pad. Reliability issues due to corrosion are dewetting and is mostly caused by Atmospheric effects (due to oxidation), lead material quality or tinned coating of Leads. This can be prevented by proper storage of components

Table 3 Faults due to inconsistent temperature

Defect Type	Accepted		Not Accepted	
	Through Hole	SMD	Through Hole	SMD
Over Heating				
De wetting				
Cold Solder Joint				
Incomplete Reflow				

in a controlled atmosphere. Our visited Industry partner stores all electronic components in Temperature /Humidity controlled stores & Dry cabinets are used for Moisture Sensitive components. The floor life of devices is specified in ERP software and alerts are given for expired components after verifying the date code, accordingly, items will be issued for manufacturing. The following steps are followed from the manufacturing end in the case of Moisture sensitive components (components with Moisture Caution Label) [14]:

1. Devices are baked and dry-packed before shipment from the factory. The packing is done using a Moisture Barrier Bag (MBB). A Humidity Indicator Card (HIC) and drying desiccant are included inside the MBB. An MSL 3 label is attached to caution that the bag contains moisture sensitive devices.
2. The shelf life of devices in a sealed bag is 12 months at 10% when read at 23 °C ± 5 °C. After MBB is opened, devices should go through reflow for board assembly within 48 hours at given factory conditions.
3. PCBs are stored in a controlled area where temperatures and Humidity are maintained at 250 °C at RH of 60% with temperature variations of +20 °C and RH of +5%.

And caution should be taken on expiry dates of the components by verifying the date code.

The corrosion defect and its acceptance criteria are shown in Table 4.

2.5 Errors in the Wiring Tracks

These faults occur in the wiring tracks connecting various components in the PCB. In the wiring tracks, we have shorts, open, scratches, etc. as shown in Table 5. Minimum spacing between tracks must be maintained. If the etching is not proper it would lead to track shorts which lead to wrong logic or shorting. Also, excess etching will lead to track cuts. Lifting of the track is due to excess pressure with heat during soldering or due to external force, which is not desirable. Process problems and peeling of

Table 4 Corrosion defect

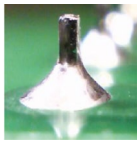
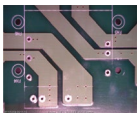
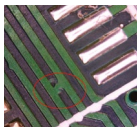
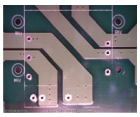
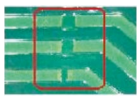
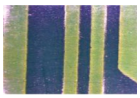
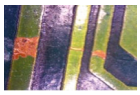
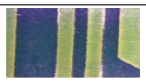
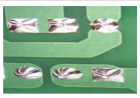
Defect Type	Accepted		Not Accepted	
	Through Hole	SMD	Through Hole	SMD
Corrosion		Not applicable		Not applicable

Table 5 Errors in the wiring Tracks

Defect Type	Accepted		Not Accepted	
	Through Hole	SMD	Through Hole	SMD
Track Short				
Track Cut				
Track Lifting				
Exposed Bias Metal				
Scratches				
Cleaning				

masking caused due to Exposed bias metal, which should be avoided. Also, scratches during the process will lead to the exposure of the base metal. If cleaning is not proper, excess material will be left on PCB that will lead to shorts, etc. [9].

2.6 Component Faults

Component errors occur due to process errors and if these errors are noticed the component placing process has to be looked into and rectified. The components have to sit properly on the PCB for the manufacturing processes to be proper. It is not desirable to have lifting of component during the soldering process which occurs due to component improper placement or profile issues. Physical damage to the component might occur during soldering processes or during temperature Stress test and we need to avoid it. It is due to Programming error(s) that some components might be misplaced or missed during fabrication. Reverse Mounting error might occur either due to programming error or due to reverse mounting of the components. Also, wrong feeding of components will lead to mounting error. Component Alignment defects occur due to soldering mistakes and profile issues. Similarly, the Height Mounting error occurs due to a Mounting issue during fabrication. Also, Extra Mounting defects are caused due to Programming errors. The various types of defects due to component faults are shown in Table 6 [9].

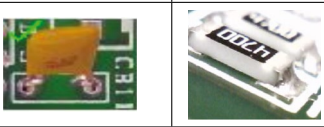
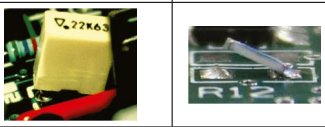
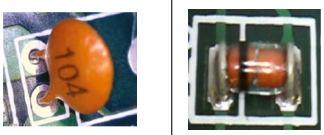
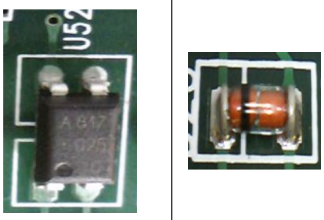
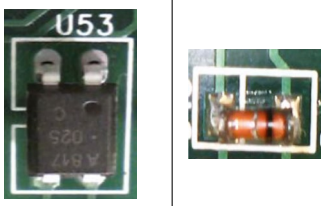
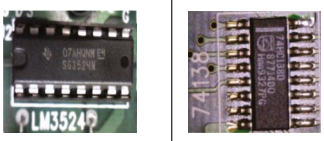
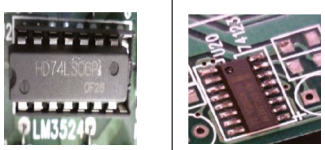
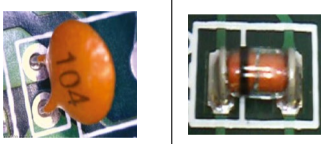
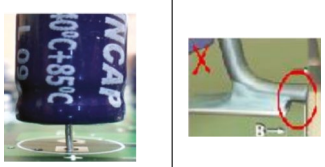
2.7 PCB Level Defects

These are the board level faults that occur on the PCB as shown in Table 7. If fixing is not proper that will affect the mechanical reliability of the board. If soldering is not proper, the wiring on the board will get damaged and might lead to electrical shorts.

3 Comparison

Of the various faults that occur on PCBs, the percentage occurrence of Open Solder Joint is the highest with about 34%, followed by Solder Bridges at 15% and Component Shift faults at 15%. Other faults include- missing components, defective electrical and non-electrical components, wrong component placement, component misalignment, inconsistent soldering, and wrong orientation from the remaining faults [15]. In this paper we have classified the

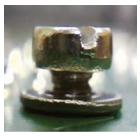
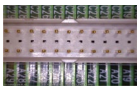
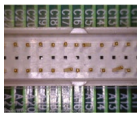
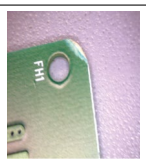
Table 6 Component faults

Defect Type	Accepted		Not Accepted	
	Through Hole	SMD	Through Hole	SMD
Tombstoing				
Component Damage				
Item Missing				
Reverse Mounting				
Wrong Mounting				
Component Aligment				
Height Mounting				
Extra Mounting				

faults into these groupings so that it would be easy for ML image classification- Bridging faults - Weak and strong, Open faults - Weak and Strong, faults caused because of temperature, wiring track faults, component faults, PCB level defects.

A Month wise defects summary is presented in Figs. 2 and 3 for the scenarios of Manual soldering and Machine soldering which were obtained from the industry as a part of Industry-academia collaboration. Defects due to manual soldering from Apr-2017 to Dec-2019 are presented in Fig. 2 and due to Machine soldering is presented in Fig. 3 for the period Apr-2017 to July-2020. The figures show the month wise PPM (no of soldering point wrong occurrences among one million points) of the top 5 defects. From the figures, it is observed that the majority of defects are Open

Table 7 PCB level defects

Defect Type	Accepted		Not Accepted	
	Through Hole	SMD	Through Hole	SMD
Fixing not proper		Not applicable		Not applicable
Pin Bend		Not applicable		Not applicable
Wiring on Board		Not applicable		Not applicable
PCB Damage		Not applicable		Not applicable

connection defects in both cases, with 1442 ppm and 568 ppm in the case of machine and manual soldering respectively. One of the steps that are involved when an open connection is made via machine soldering is printing a solder case. In this step, holes are punched where solder joint has to be formed using a stencil and then solder paste is applied. Due to the bulk production made at the respective factories, the application condition of paste and the stencil varies on continuous usage. Therefore, there are two chances of open defect:

1. The paste won't be printed properly if the stencil is not maintained properly
2. the stencil can't squeeze the paste properly if solder paste consistency is not good

To prevent the above problem, the stencil should be cleaned for every squeeze and solder paste quality should be checked to prevent it from hardening. Whereas in the case of manual soldering, the chances are comparatively less as operator gets to check these conditions manually. One way to prevent the above effect is to automate the conditions of checking the quality of stencil and cleaning it in the case of machine soldering. The least number of defects that occurs is wrong mounting in the case of Manual soldering and component damage in the case of machine soldering.

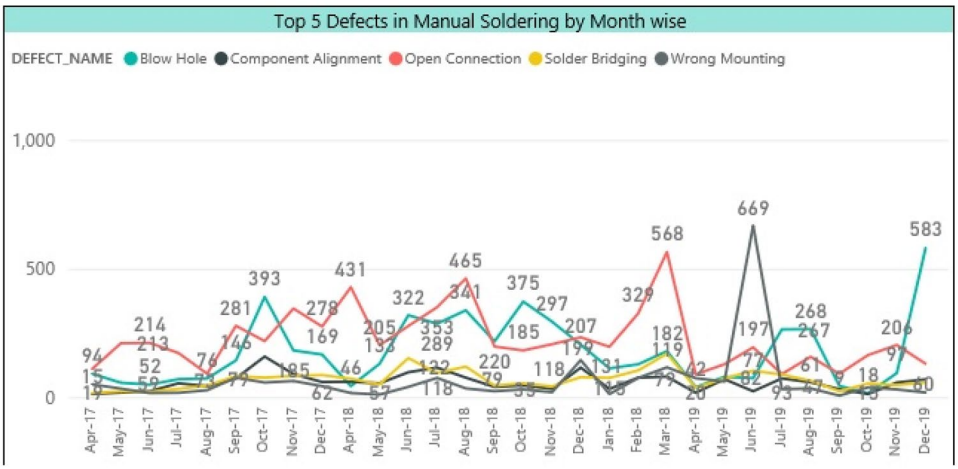


Fig. 2 Top 5 Defects in Manual soldering-Month wise

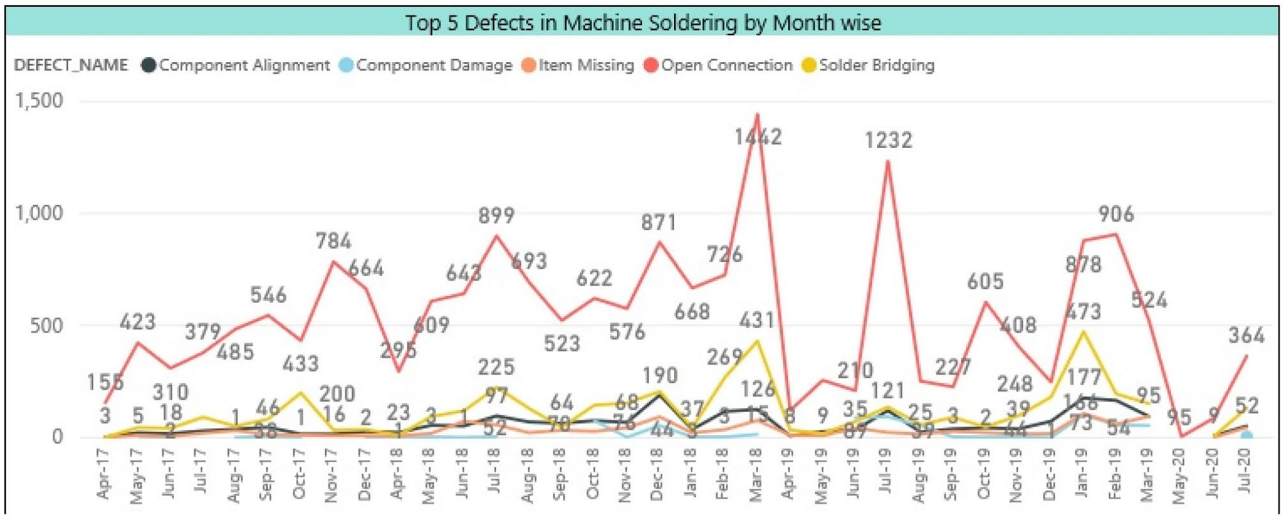


Fig. 3 Top 5 Defects in Machine soldering-Month wise

4 Conclusion

In this review paper, we have presented the various soldering and non-soldering defects that occur during the fabrication of PCBs. A total of 34 defects have been listed and for the defects, the acceptance criteria and non acceptance criteria from the industry perspective also have been elaborated. The 34 defects have been sub classified into Short defects, open defects, faults due to inconsistent temperature, corrosion defects, errors in wiring tracks, and component faults. This classification was done to help defect identification using the AI-ML technique.

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Data Availability Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Conflicts of Interests and Competing Interests The Authors declare that there is no conflict of interest, funding or competing interest.

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