Assessment of the influencing parameters of the tumble test for robustness testing of smartphones

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Abstract

In the wake of increasing attention being paid to robustness and durability of electronic products in general and smartphones in particular, the tumble test is gaining relevance when it comes to emulate real life scenarios of falls and accidental drops. Unlike other drop tests, the tumble test is a fast way to simulate random falls close to real life accidents. There is currently a standard (IEC 60068-2-31) for such testing that sets certain parameters (i.e. the spinning speed, the fall height…) depending on the size and weight of the device under test but leaves enough room for calibration.
This study aims to take a closer look to the effect of a variation of those parameters in the experiment. For that, several devices are tested under different conditions and indicators like the fall statistics are collected and then correlated with the test variables. To achieve this, a high-speed camera is used in order to be able to see what happens during impact.
As an outcome, this leads to a better understanding on how these parameters can lead to a more accurate simulation of real life conditions as well as the current limitations of the procedure.

1 Introduction

A common approach to evaluate the hardware reliability of electronic devices such as smartphones is to use standardized tests. For specific failure modes or specific field loads different tests are used. Based on the hardware features of a smartphone and common use cases, typically devices are tested against physical shock, water ingress and durability of connectors [1][2].

To test the structural integrity of smartphones against physical shocks caused by accidental drop a free fall test is often used. This kind of tests are characterised by offering a very controlled environment with a set of precisely definable parameters, such as drop height and impact surface. On the other hand, the tumble test allows automated testing of a device with random drop orientations and many consecutive impacts. Smartphone manufacturers and consumer organisations are using those tests for quality control and product evaluation. The standard IEC 60068-2-31 (and others [3][4]) defines parameters for both, the free fall test and the repeated free fall test for small electronic devices, but not for smartphones in particular. In this paper parameters of the repeated free fall test (tumble test, based on IEC 60068-2-31) are investigated for robustness testing of smartphones. Therefore understanding the effect of such parameters helps to optimize the tumble test.

2 Test environment

The standard IEC 60068-2-31 defines some of the parameters for the repeated fall test conforming a baseline general test environment, which can be summarised as the following. The tester device is a tumbling barrel, which is designed, following the standard, for the probe to fall from already defined heights of 0.5 m or 1 m with every turn. The impact surface is hard wood covered by a steel plate. The rotation speed allows a reproducible impact of the probe in the middle of the impact area. A conclusive evaluation of the test regarding suitability and reproducibility is not available yet.

3 Test parameters

The IEC 60068-32-1 standard sets values for some of the test parameters while others are more open to be specified depending on the device under test. This section will therefore show a brief description of those and comment on their suitability for smartphone testing. The next section will then put the focus on the considered main test parameter.

3.1 Fall height

As commented above, the standard sets the fall height for the tumble test at either 500 mm or 1000 mm. Unlike the free fall test without repetition, in which greater flexibility is shown, the tumble test fall height is limited by the structure of the tester itself, which is a barrel

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of fixed dimensions. For setting the height, the severity level of the test has to be considered i.e. how hard the test conditions are for the device under study. The standard provides a suggestion of severity levels, based on fall height and probe weight. This should be set keeping in mind the expected conditions in which the real life fall is expected to occur.

3.2 Spinning speed

The standard sets the required spinning speed at around 10 turns per minute. During the tests within the scope of this paper, it has been seen that this is the spinning speed needed for the probe to fall in the centre of the impact surface, avoiding possible interference like hitting the walls and allowing recording and/or visual inspection of the impacts. Variations of this value could however be justified either by practical reasons or in order to adjust the severity level of the test alongside other parameters.

3.3 Surface properties

The IEC 60068-32-1 standard sets an impact surface consisting of a steel layer backed by hardwood. The standard does nonetheless leave room open for changes in this regard if relevant specifications require otherwise.

During use, accidental falls of smartphones can occur onto various surfaces (i.e. wood, concrete, tiled floors, carpets…) and therefore the surface on which the test is performed should be accounted for when assessing the severity level of the test as well.

3.4 Number of falls

The test standard offers values between 50 and 1000 drops to choose from. The number of falls should be determined based on the specific device under test.

3.5 Sample size

The standard does not specify the amount of samples for carrying out the test. When determining the sample size for smartphone testing two aspects have to be considered. On the one hand, the statistical significance of the results. High variation between individual devices' results means that several devices for testing might be needed for having enough certainty. On the other hand, the usability of the test might impose its own practical restrictions. For instance, if the tumble test is to be used in market surveillance for smartphones, the use of numerous probes might be impractical.

4 Functional Requirements

The standard defines the failure of a device as an inability to fulfil the functional requirements set in advance, which the standard does not specify. The list of failures that can occur during a tumble test can be divided into four categories, as they relate to the usability of the smartphone, defined as follows:

Class I: Failures that make any use of the phone completely impossible, e.g.: display sensitivity loss.

Class II: Failures that make a normal use of the phone impossible, e.g.: irresponsive buttons, severely shattered front glass.

Class III: Failures that make a normal use of the phone inconvenient, e.g.: ingress protection loss, moderate glass cracks.

Class IV: Failures that affect the aesthetic appearance of the phone but do not alter its usability, e.g.: scratches and aesthetic impairments.

In order to define the severity level appropriate for smartphone durability testing, the pass/fail criteria for the tumble test is a relevant aspect to be defined. Setting responsiveness as the central criteria, the appearance during test of failures belonging to classes I and II could be read as a bad result while class IV failures could be read as a pass. As for class III failures, they could be further subdivided based on the expected use of the device or serve as a basis for a grading system that allows differentiating between better and worse performing smartphones.

5 Effects of fall height

From all parameters commented above fall height and number of falls are considered to be the most relevant, since the standard allows for variation of those and they directly affect the severity level of the test. Functionality requirements and sample size are considered not to be part of the test conditions per se but rather of the context of the test, which will vary depending of the intended use and technical capabilities of the tester.

Due to technical limitations this paper has focused on the fall height more than the number of falls. The number of falls was set to 200, as it was necessary to achieve the highest number of falls for a certain number of devices under test for a limited time frame.

5.1 Methodology

The tests were conducted using a tumble tester which meets all requirements to perform the repeated fall test according to DIN EN 60068-2-31. In order to further analyse the devices' behaviour during the moment of impact, a high-speed camera was used. It was connected to the trigger output of the tester to record a short clip with every rotation. Also external lighting equipment was used, which produces no flickering effect, while filming with a high-speed shutter. A maximum of 200 falls was defined for each test device. If

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the damage of the device was too high (e.g. extended glass shattering) the test was stopped before the maximum number of falls was reached. The test conditions are listed in Table 1.

Fall height	500 mm / 1000 mm
Rotation speed	10.6 rpm
Max rounds per device	200
Frame rate	2000 fps
Shutter speed	1 / frame rate
Resolution	768 x 768 pixel
Clip duration	1500 frames / impact

Table 1: Test conditions

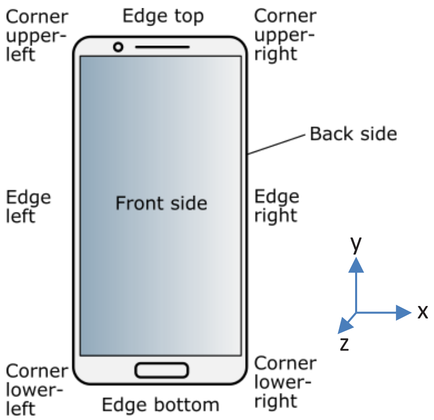

Figure 1: Defined impact areas on the smartphone

Areas on the smartphones were defined to differentiate the impact areas during the test. The first differentiation was made between impact on the front side (display), back side or frame. If the impact angle towards the front is smaller than 45°, the impact is counted as a front side impact. The same applies to the back side. The frame is further divided into subsections (see figure 1). If the impact is on the frame, the impact angle to the next edge has to be smaller than 15° so that it counts as an edge impact. Figure 2 shows the impact of one test device on the lower right corner. In this case the impact angle to the right edge is more than 15°.

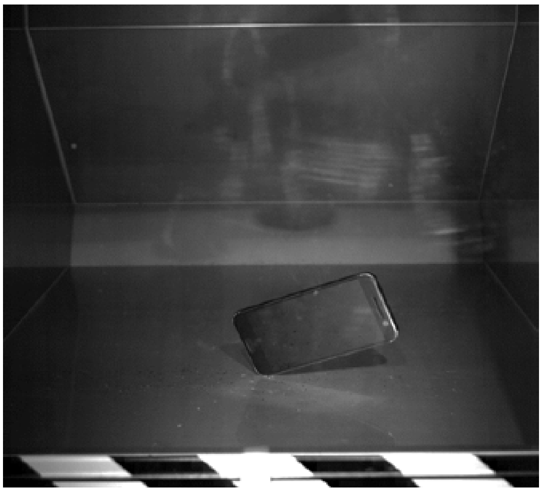

Figure 2: Moment of impact; smartphone in tumble test

5.2 Test samples

Five smartphone models were selected, with attention to a wide range of sizes. Since there are different combinations of materials used to manufacture the smartphones, they also differ according to their weight, see Table 2.

Although each of the devices under test has a different design, most smartphones share a very similar internal structure and its different parts are arranged very similarly. A balance test performed in-house, shows that the center of mass of all evaluated devices is very similar and close to the middle of the devices, see Figure 3. For model A and B it is slightly shifted to the lower half. For model C, D and E it is slightly shifted to the upper half of the device. For model E it's also shifted to the left side.

The weight distribution along the z-axis depends on the smartphone design. The front and back cover of Model A, B and E are made of glass. The back cover of Model C is made of polymer. The back cover of Model D is combined with the frame and made of aluminium. These material differences suggest that the mass could be distributed unevenly between the frame and the back for some models.

Table 2 shows a summary of the physical specs of the models under study showcasing variety in terms of size and weight, with models A to C in the higher end and D and E being the lighter ones. There are also differences in the used housing materials, the possible effects of which are commented below in Impact Orientation.

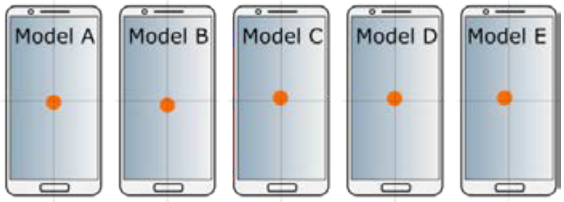

Figure 3: Centre of mass of evaluated devices

ID	Display size	Body size (mm³)	Weight
A	5.8"	144 x 71 x 8	177 g
B	6.2"	158 x 78 x 8	208 g
C	6.5"	158 x 72 x 10	189 g
D	5.2"	146 x 72 x 9	161 g
E	5.1"	143 x 71 x 7	138 g

Table 2: Properties of the smartphone models

5.3 Impact orientation

The tumble test was conducted with one specimen for each of the five models and with both fall heights, 50 cm and 100 cm. The relative share of impact orientation can be seen in Table 3.

Model	Fall height	Frame	Frontside	Backside
A	50 cm	100,0 %	0,0%	0,0%
	100 cm	97,0 %	3,0%	0,0%
B	50 cm	100,0 %	0,0%	0,0%
	100 cm	100,0 %	0,0%	0,0%
C	50 cm	100,0 %	0,0%	0,0%
	100 cm	93,5 %	0,0%	6,5%
D	50 cm	84,5 %	11,0%	4,5%
	100 cm	72,0 %	15,0%	13,0%
E	50 cm	100,0 %	0,0%	0,0%
	100 cm	97,5 %	0,0%	2,5%

Table 3: Percentage of impact orientation

For all models and both drop heights, most impacts were registered in the frame. The exception was model D, which for both fall heights showed a relevant share of the impacts happening on the front- and backside of the smartphone. In all cases it is also seen that for the 1 m fall height, the impacts are not exclusively concentrated on the frame.

In figure 4, frame impacts are shown in greater detail, for a fall height of 100 cm. Among the tested smartphone models different behaviours can be seen. For models A and B, most impacts were registered in the long edges i.e. right and left edges, followed by the lower corners. Model C shows a similar trend for the lower corners.

Model D displays a different behaviour, with most impacts being registered on the upper part of the device most prominently the top edge. For model E, the long edges (especially the right edge) show the highest impact incidence, followed by a slight trend towards the upper side i.e. upper right and left corners.

As explained above, the mass centre of the devices are slightly shifted to the upper end for models C, D and E and a bit towards the lower end for models A and B. This does correlate with the impact distribution of all models with the exception of model C. The center of mass on the x-axis for models A, B, C and D is positioned fairly in the middle of the device. As a result one would expect a random distribution of impacts on the left and right side. This can be seen in the results of the experiment. Model E has its centre of mass slightly shifted to the left side and here the experiment shows a higher accumulation towards the right.

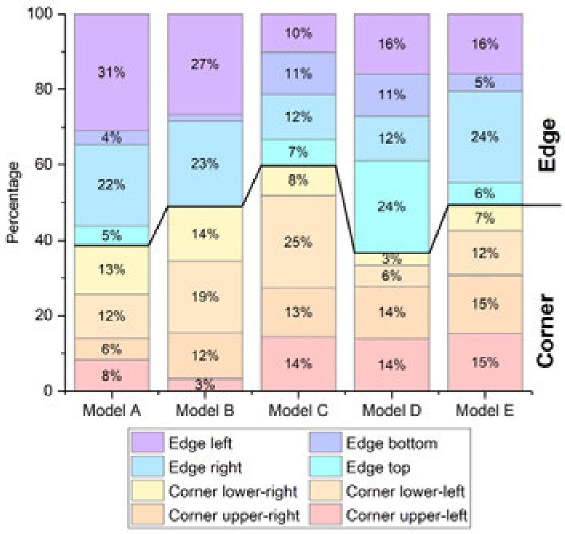

Figure 4: Distribution of impact areas only on frame (Fall height: 1000 mm)

The material choices and their combination, as mentioned before, might imbalance the centre of mass in z-axis. This could lead to a greater tendency towards spinning while falling. Device B would then show a stronger tendency to fall directly on the frame while device D would show more impact variation (due to the mid-air spinning). This seems to be the case as seen in Table 3. This spinning would then result in a more random distribution in figure 4, for instance.

The same impact orientation analysis was conducted for the fall height of 50 cm (figure 5). The distribution differs from 1 m fall height. For model A, B, C and E the share of impacts on the edges increased. And for all models the distribution is more homogeneous, in accordance with the observations recorded in Table 3. A possible explanation is, that the effect of the imbalance and the aerodynamic behaviour during fall are increasing with the increased fall height.

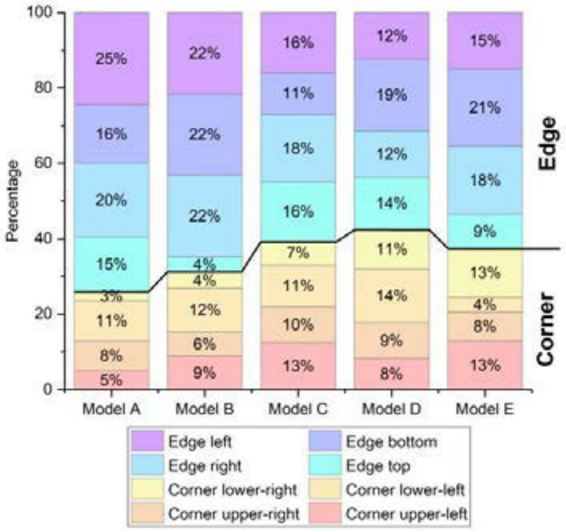

Figure 5: Distribution of impact areas only on frame (Fall height: 500 mm)

In order to give context to the described results, the sample size of model A was increased to 15 devices. Just like in the individual tests, the most impacts (accumulated for all samples) are registered in the frame (98.8 %). The impact distribution on the frame as mean value with a confidence interval of 95% is shown in figure 6.

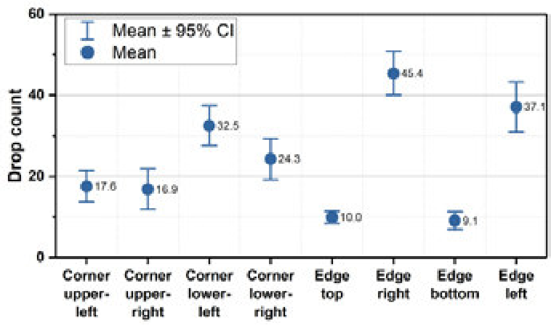

Figure 6: Impact distribution for model A

The aggregated results do not differ greatly from the individual ones (+/- 5% at most and almost none at times) and the main hotspots are still coherent with what is shown in Figure 4, which suggests greater uniformity between individual tests.

6 Conclusions

From the results presented above, the following facts were observed:

- Different smartphone models show different fall orientation patterns.
- For both 100 cm and 50 cm heights, most impacts are predominantly on the frame for all tested devices.
- With 100 cm fall height, the impacts on the frame edges and frame corners are rather balanced while the 50 cm height shows greater edge impact incidence. With 100 cm fall height the difference between models is more pronounced.

Additionally, based on the observations, the following hyptheses and conclusions were made:

- Mass distribution has been studied as main hypotheses to explain model-level differences.
- When given enough time/space during fall (1 m) smartphones tend to show a fall orientation pattern coherent with their mass centre position.
- The material combination chosen for the housing structure is also suggested as a potential explanation for the divergences in the frame-front-back impact distribution.

At this point it is worth noting that this paper has focused on fall orientation. Although attempts have been made to measure and modelling the impact stress of a smartphone for drop test conditions [5][6], shocks by fall are a complex phenomenon and there is not necessarily a direct correlation between the durability and the impact orientation. It is therefore advised to take those conclusions with caution since they do not necessarily work as a proxy for durability.

To conclude, we would like to make some final remarks on what those results imply in relation to the adequacy of the test conditions defined in the standard to the smartphones product group:

- Based on the design and behaviour differences as well as the openness of the functionality requirements, it could be the case that subgroups should be made for the test within the smartphone product group, based on main features, key design aspects or expected use.
- The differences in fall orientation between 1 m height and 50 cm height suggest that the same devices could perform differently in both, making this a relevant aspect of the test process.
- Also the results suggest that from the design of the smartphone the major impact point when falling can be estimated. This does not apply to all tested models, however, design rules may be derived by further studies.

In this study the parameters of the tumble test were discussed. Especially the effect of the fall height on the test was shown by experiments. In future works the influence of the impact surface conditions and the statistical relevance of the test has to be analysed.

7 Literature

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