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RESEARCH

Running-in Analysis of Transmission Gear

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A B S T R A C T

The automotive industry's impact on development and improvement, reliability and lifetime, of components is significant. Automotive market encourages small and medium enterprises (SMEs) to enter this market, which is for SMEs a challenge to meet specified product quality. In this study, running-in wear analysis of transmission gears is conducted, which is rarely discussed in literature. Based on this study, one can make recommendations to SMEs to improve their product. Examination tests between an original equipment manufacturer (OEM) gear and SMEs gear product have been made. Results showed that mass and chemical composition are same. A clear difference between SMEs and OEM gear was seen from surface roughness and material hardness tests. SMEs gear exhibits a failure mechanism, and OEM gear does not indicate any failure indication during running-in period.

1. INTRODUCTION

The automotive industry is one of the oldest, largest, and most powerful in Indonesia that consist of assembly, body, and parts. Market maintain to restore from 1998 crisis with an ascending number of study (around 445 as of 2005); expanding workforce (predicted 250.000 to 400.000, with about 100.000 to 150.000 workforces in second and third-tier constructing) and rapidly rose in added value expenditure [1]. Domestic market demand has hysterically been motorist for automotive assembly and spare part corporation. This tendency extend until now as domestic component market has been continued by solid growth in motorcycle and car assembly markets and subsequent rose in market of replacement parts [2]. In rural and urban areas, motorcycle has appear as a feasible substitute transport approach because of its affordability, loan support from funding corporation, and fuel efficiency [3,4]. Several domestic small to medium enterprises (SMEs) have enrolled market to meet this ever-growing demand. These SMEs products are generally relatively low-quality as an alternative to purchaser who cannot or do not want stand for finest original branded component. In addition, they cannot challenge deadlocked by best quality constructor for original display because of quality problem. Transmission gear is one of automotive components produced by SMEs [5].

In this study, running-in experiments of motorcycle transmission gear were conducted to compare quality between a SMEs product and an original equipment manufacturer (OEM) product. Many factors are governing the quality of gears and also their failure. Failure analyses of gears have been conducted by many researchers, for instance, pinion [6] and idler gear [7]. Scoring, wear, pitting, plastic flow and teeth breakage/fracture are gear failures caused by design errors, improper installation and operation [8]. When contact between pinion and gear's teeth-asperity occurred because of lubrication failure, scoring happened [9].

The interacting surfaces may cause damage due to progressive removal of material, also known as wear [10–12]. Wear causes gear to weaken due to increased surface roughness and increased clearance at mating interface [13]. High excess loads (from impact loads and static loads) also cause tooth fractures [7,14]. According to ISO 10825 there are many failures mode classification for gears. In this study failure of running-in wear as indications of surface disturbances is focused.

In order to prevent or obtain gear resistance to failure, gear treatment is required. Resistance to gear failures such as pitting, wear, and fatigue can be achieved by hardening tooth surface due to gears' heat treatment [15]. Heat treatment dramatically affects quality and mechanical performance of gears. Where cost, durability, and reliability are directly related to it [16]. Specific thermal treatment that increases metals' hardness by rapid heating and subsequent quenching is called hardening process [15]. Carburizing and induction heating are two methods of hardening gears that are commonly used [17]. Carburization is process of spreading carbon onto surface of steel components carried out at high temperatures, where after quenching, austenite produces a hardened martensitic surface [15]. Induction heating is a process of increasing hardness of steel surface obtained from rapid cooling of steel surface, previously subjected to heat from electromagnetic fields and induced currents [18].

However, running-in wear failure analysis of gear is rarely published. Mihailidis et al. [19], for instance, studied the wear of machine elements during running-in and after running-in. This paper presents the failure analysis of a motorcycle transmission gear during the running-in period to reveal mechanical parameters such as material property, roughness, and others contributing to gear's failure.

2. RUNNING-IN PROCESS

Changes in couple asperities condition generally occur when pair of asperities are weighted for the first period and moved relative to one another. These transformations are commonly a consolidation of several aspects, like axes positioning, architecture modification, an adjustment in surface coarseness, and even up of several mechanical and chemical properties between expressive asperities, like micro-hardness test producing by effort hardening or formation of oxide layers and another boundary layers. These modifications have been modified to decrease energy flow, in both mechanical or chemical, among progressive asperities. Modification between start-up and steady-state are correlated by running-in (also called breaking-in or wearing-in). Despite in terms of conservation, wear is ever troublesome, outstanding running-in wear is supported alternately evade [20].

Many literature works defined running-in as removing high spots in interacting asperities by wear or plastic deformation under contained conditions of running, offering enhanced conformity and decreased possibility of film breakdown during normal procedure [20]. Running-in occurs in first period in lifetime of a rolling or sliding contact of a lubricating system, representatively shown in Figure 1. Before running-in, many couple of interacting asperities in, for detail, a new engine are not 'connected together'. During running-in period, high spots left from final machining operation are decrease by plastic flow, voids are filled, and overall construct are paired. Higher temperatures usually cause greater wear rates. However, as asperity become smoother and more prominent asperities are flattened, wear rate falls to a steady-state. Furthermore, higher asperities are rubbed off. This mechanism is also called truncating or censoring height distribution.

Wear rate decreases until it reaches normal steady-state wear rate for design interact couple. Wear rate during running-in, even when misalignments are minimal, is higher than during normal running. A steady low wear rate regime is maintained for designed operational life. Wear rate may increase again once running duration becomes adequately long for a fatigue process to exist in upper layers of loaded surface. Once wear particles because of fatigue wear accumulate asperity, it will wear-out, for example total failure performed.

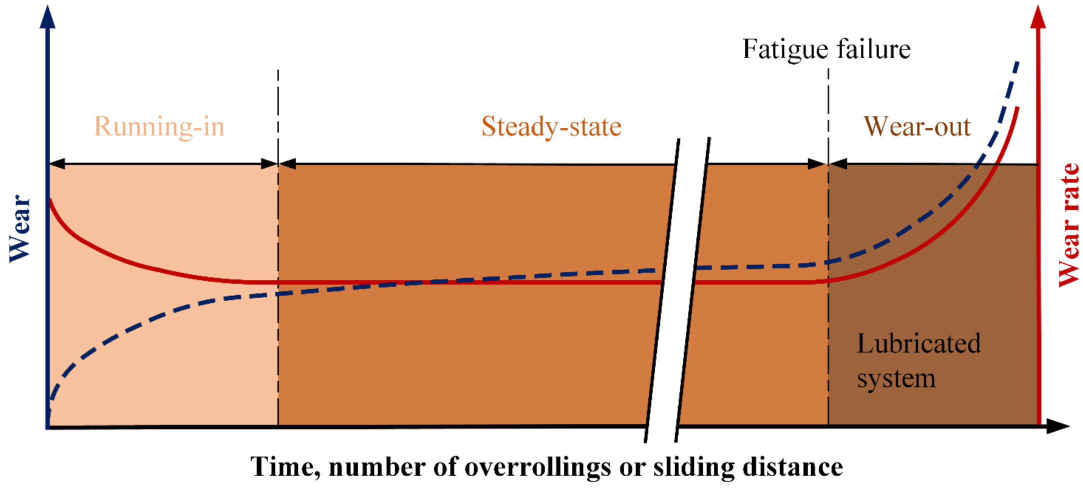

Fig. 1. Wear behaviour diagram as a function of time, number of overruling or sliding distance of contact under constant operating conditions [20,21].

3. RUNNING-IN EXPERIMENT OF A TRANSMISSION GEAR

Running-in experiments of second transmission gear of motorcycle were performed by employing a modified motorcycle engine, as shown in Figure 2. The engine is taken from a motorcycle and is placed on a particular setup. In this setup the load of 250 N and the speed of 2500 rpm were applied.

Transmission gears from two manufacturers, OEM and SMEs, were tested in running-in experimental setup. Running-in experiments were executed by running gear for 30, 60, and 3600 minutes for every product. Commercial lubricant was used in experiment. Before running transmission gear, several parameters wear measured, such as hardness, surface roughness, SEM, and others. These measurement steps were repeated after running-in test.

Continue in the next running-in time, a new pair of gear specimen was used. Running-in test does not use one specimen for several running-in time condition to avoid misalignment or other contact condition due to replacing process. When contact condition changes, running-in behaviour changes, so data cannot be incorporated with previous running-in data.

4. RESULTS AND DISCUSSION

4.1 Mass measurement

Table 1 shows measurement results of gears tested. It can be seen that there is almost no difference between mass before running-in and mass after running-in for both OEM and SMES product. Mass of SMEs product, either main gear or counter gear, is lower than that of OEM product.

4.2 Chemical composition of material

Run-in gear chemical composition of OEM and SMEs product are presented in Table 2. Gear material samples were tested using spectrometer. There is almost no difference between OEM gear and SMEs gear. It means that preparation of material composition of SMEs is relatively good.

4.3 Surface roughness measurement

Table 3 presents measured surface roughness values Ra of gear before and after run-in tests using SURFCOM 470A. For all running-in gears, there is a reduction in surface roughness value. This reduction becomes higher as running-in time increases, meaning that running-in process is still in progress. The initial roughness value of SMEs gear product is much higher than OEM gear product, especially for counter gear, which can reach a value of 2.44 μm. Even though there is a surface roughness reduction after running-in process, surface is still very rough for automotive gear. Difference in roughness between initial main gear and initial counter gear is also significant. Average roughness of SMEs' initial main gear is about 1 μm and average roughness of initial counter gear is about 2 μm. For OEM gear, difference between average roughness of initial main and counter gear is less than 0.1 μm. This roughness magnitude will contribute much to failure gear during running-in process.

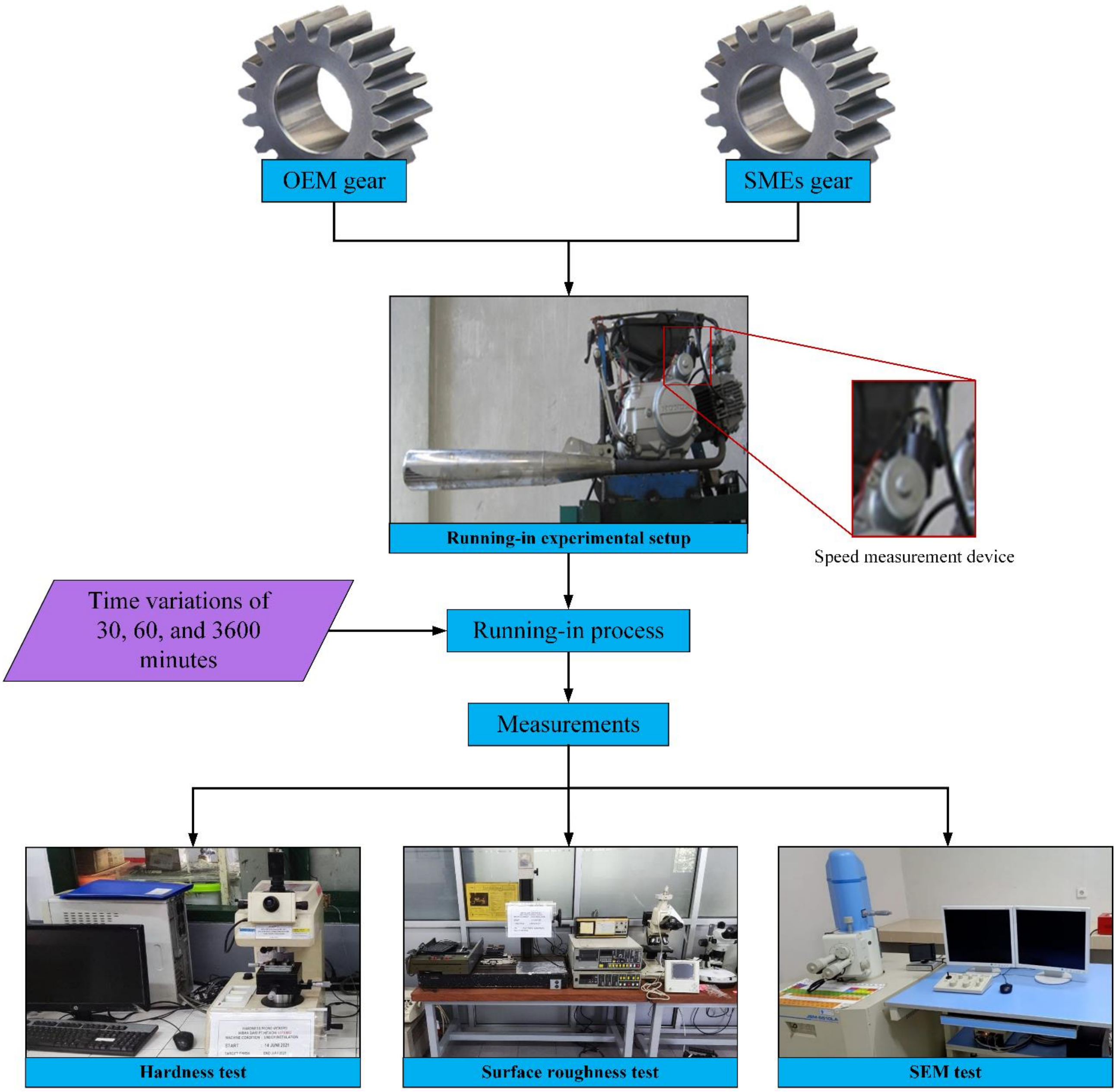

Fig. 2. Workflow of running-in experiment of transmission gear.

Table 1. Mass measurement of gear (gram).

Product	Gear	30 minutes		60 minutes		3600 minutes	
		Before	After	Before	After	Before	After
OEM	Main	43,730	43,728	43,611	43,588	43,734	43,726
	Counter	171,834	171,831	171,853	171,476	171,968	171,946
SMEs	Main	39,858	39,720	37,681	37,536	38,423	38,436
	Counter	165,043	165,001	142,545	142,536	163,050	163,002

Table 2. Chemical composition of the gear material (wt%).

Element	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co
OEM	97	0.44	0.284	0.812	< 0.0050	0.0175	1.07	0.17	0.0426	0.045	0.0093
SMEs	96.9	0.409	0.25	0.771	0.0089	0.0217	1.03	0.153	0.129	0.0324	0.0054

Element	Cu	Nb	Ti	V	W	Pb	Ca	Zr
OEM	0.102	0.0089	0.0066	0.0102	0.0568	< 0.01	0.0005	0.003
SMEs	0.0152	0.0081	0.0045	0.009	0.0593	< 0.01	0.0007	0.0039

Table 3. Surface roughness Ra of the gears before and after running-in (μm).

Product	Gear	30 minutes		60 minutes		3600 minutes	
		Before	After	Before	After	Before	After
OEM	Main	0.78	0.60	0.81	0.55	0.67	0.48
	Counter	0.76	0.56	0.74	0.58	0.74	0.54
SMEs	Main	1.14	0.84	1.03	0.87	1.02	1.61
	Counter	1.67	1.28	2.44	1.69	2.09	1.84

4.4 Micro hardness of gear

For hardness investigation, micro hardness was measured along with distance from surface to substrate material to determine hardness distribution on a cross-section perpendicular to contact surface using MHV-2000 microhardness tester. Hardness distribution results for OEM and SMEs gear are presented in Figure 3. Surface contact is used as origin of measuring direction coordinate. Measurement was taken for every 200 μm of distance. OEM product's surface hardness is higher than SMEs product for both main and counter gear, and difference hardness between them is very low.

In contrast, different hardness of main and counter SMEs product is high. This different hardness will contribute to wear or surface plastic deformation. For specific contact load, failure possibility of contact pairs with significant difference hardness is large. It is because a hard surface will act as a cutter to the softer one.

It can be seen from Figure 3, distribution of hardness is decreasing as distance from contact surface to substrate is increasing. This behavior is due to applied surface hardening mechanism. For both main and counter gear of OEM product exhibits a good hardness distribution. Hardness distribution of SMEs product is unpredictable. For counter gear for instance, hardness value is decreasing from contact surface. However, for particular distance hardness value is increasing and then decreasing again. Material homogeneity is probably cause of this phenomenon.

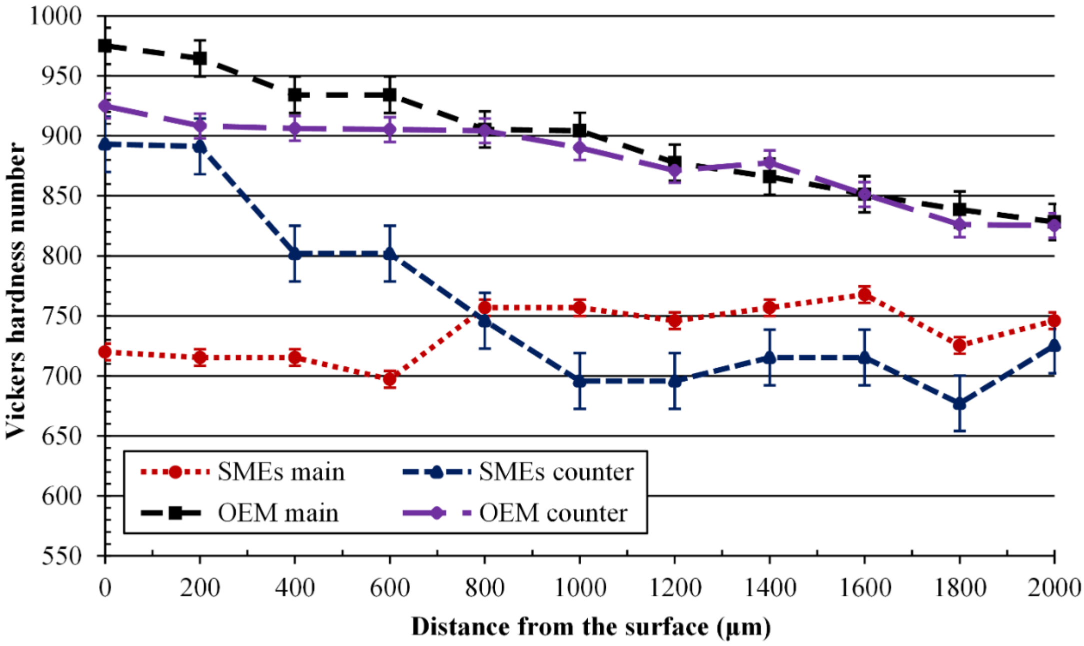

Fig. 3. Hardness profile along surface to substrate distance.

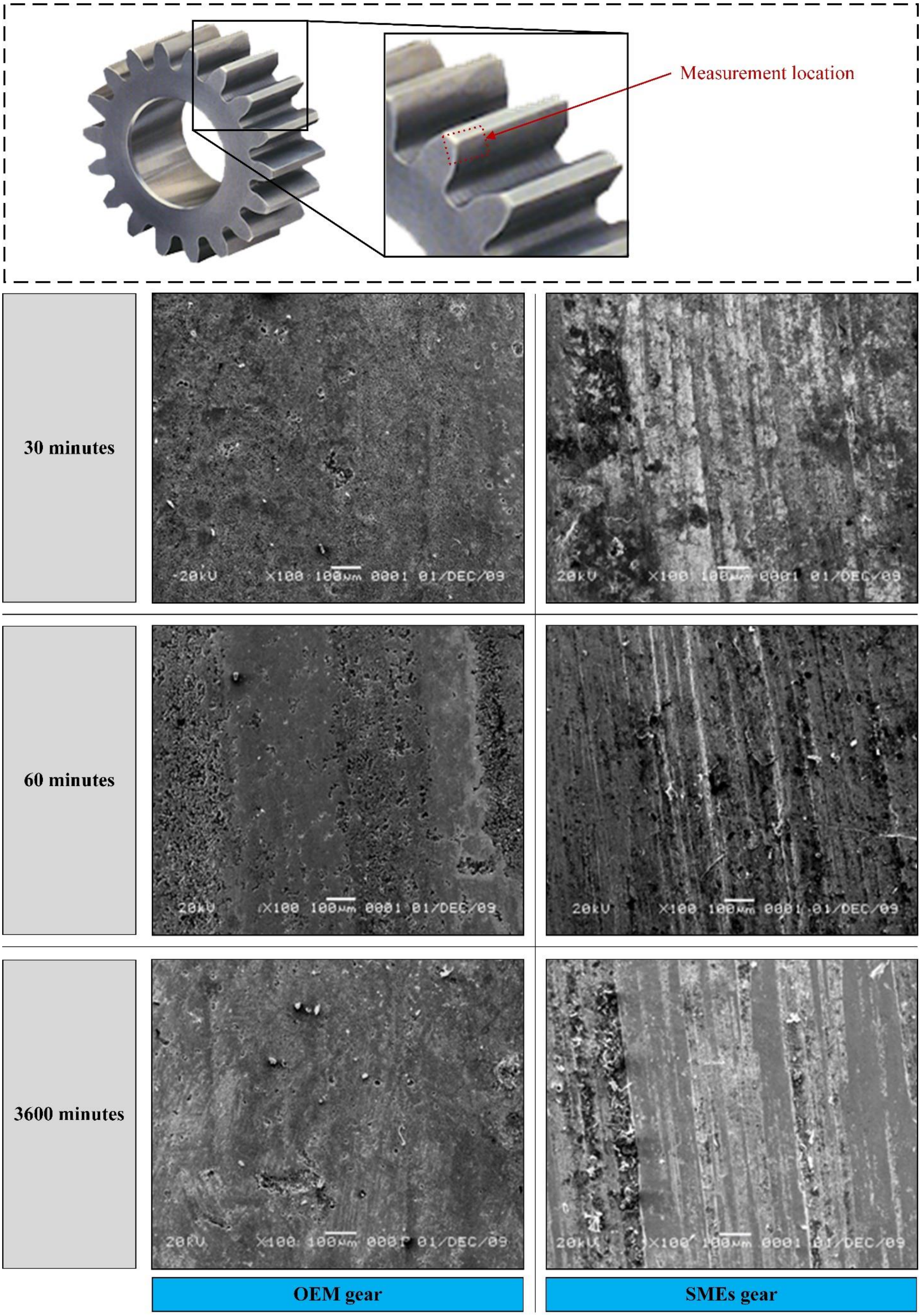

Fig. 4. SEM analysis of OEM and SMEs gear for running-in period at 30, 60, and 3600 minutes.

4.5 Microstructure examination

Figure 4 shows scanning electron microscope (SEM) analysis of OEM and SMEs main gear after running-in period of 30 minutes, 60 minutes, and 3600 minutes by employing the JSM-6510 SEM. From this microstructure examination, it can be seen that as running-in period is progressing microstructure of contacting surface is become smoother. Many scars on surface are presents in SMEs gear. This massive scar is an indication of surface failure. If this surface is used for long-term running, fatigue, crack, or other surface damage mechanism will occur.

5. CONCLUSIONS

Experimental investigation for running-in failure of a motorcycle gear transmission has been conducted. OEM and SMEs gears have been used in this investigation tests and compared by mass measurement, chemical composition, surface roughness, material hardness, and SEM analysis.

For the mass measurement and chemical composition results, there was almost no difference. The significant differences are the surface roughness and the material hardness. SMEs gear exhibits a failure mechanism and OEM gear does not show any failure indication. Macro plastic deformation of SMEs product is clearly observed from the SEMs analysis.

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