

Research Article

# Comparison of Water Discharge Performance of Motorcycle Tires with Different Tread Patterns by Applying CFD (Computational Fluid Dynamics) Technique

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(First received December 16, 2022 and in final form April 13,2023)

**Reference:** Comparison of Water Discharge Performance of Motorcycle Tires with Different Tread Patterns by Applying CFD (Computational Fluid Dynamics) Technique. The European Journal of Research and Development,3(2), 1–10.

## Abstract

*The tire is one of the most important vehicle parts that provide contact between the vehicle and the road surface together with the air it carries in it. Some traffic accidents are due to driving performance on the wet road surface. Aquaplaning on water occurs when depressions and sloping areas on the asphalt become filled with water, causing it to accumulate. When a vehicle passes over a puddle, its tires lose contact with the ground, causing it to slide instead of tire pattern channels helping roll on the water. This can cause problems with water drainage. When a vehicle passes over a puddle, its tires lose contact with the ground, causing it to slide instead of roll on the water. This can cause problems with water drainage. For this reason, it is extremely important to design the pattern on the tires properly. The pattern channels on the tire help to evacuate water by passing it through the channels formed on the asphalt surface. However, in cases where the amount of water is high, the pattern channels will be forced after a while and lose contact with the ground, as they cannot discharge all the water bodies. For this reason, it is extremely important to design the pattern on the tires properly. The study analyzed the water evacuation effects of motorcycle tires with three different tread patterns on wet surfaces, taking into account different factors such as contact angles, driving direction, and driving speeds. The data obtained from the study indicate that the tread pattern design has a significant impact on the aquaplaning performance of tires on water surfaces.*

**Keywords:** CFD (Computational Fluid Dynamics), Tyre, Motorcycle, Hydroplaning, Water Evacuation

## 1. Introduction

Motorcycle tires: braking on wet surfaces, aquaplaning, and driving control performances are the most important tasks of tires. When a vehicle enters the wet road surface rapidly, it increases its hydrodynamic pressure and when it exceeds the contact force, aquaplaning takes place on the water surface by making a sliding motion instead of a rolling motion on the water [1]. Basically, the driving and braking performance of the tire also deteriorates due to the presence of hydrodynamic pressure. Therefore, tire pattern design is important to minimize hydrodynamic pressure [2]. Using the CFD analysis method, it is possible to examine the interaction between the tread pattern and the wet ground. Thus, the performance of the designed tread pattern can be determined before production [3]. In studies on aquaplaning, methods based on observation and experiments were generally used. Recently, many parameters have been obtained more precisely with the development of software codes in the computer environment to solve the complicated situations encountered [4]. A generalized formulation of the Navier-Stokes equations is used to simulate the interaction between biphasic air and water flow and the tire [5,6].

The tire's contact surface shape and the designed tread pattern push water forward and expel some of the puddles. Water leaking between the contact area and the road surface settles in the grooves of the tread pattern. This allows the tread to break up the residual water film and re-establish contact with the road surface. This three-stage water distribution corresponds to three different transition zones [7,8] as shown in Figure 1; hydrodynamic zone A (tire fully floating), viscous-hydrodynamic zone B (tire partially floating), and full contact zone C (tire directly connected to the road). The definition of these zones depends on the depth of the water and the speed of the tires. The section of a tire moving at a constant speed, where it first encounters water, creates hydrodynamic pressure when the kinetic energy of the water meets region A.

As a result, the contact surface water of the tire enters the pile and as soon as the tire surface cannot break the surface tension of the water, the tire begins to move on the film layer of the water. In contrast to zone A, which has hydrodynamic pressure, zone B is dominated by the viscous-hydrodynamic pressure of water. It is seen that the viscous-hydrodynamic effects of the water in zone B were not taken into account in this study, since the water depth to be considered here is high. Water viscosity is important when it is necessary to use flow analysis where the water depth is not large and the effects of road surface properties are observed [8].

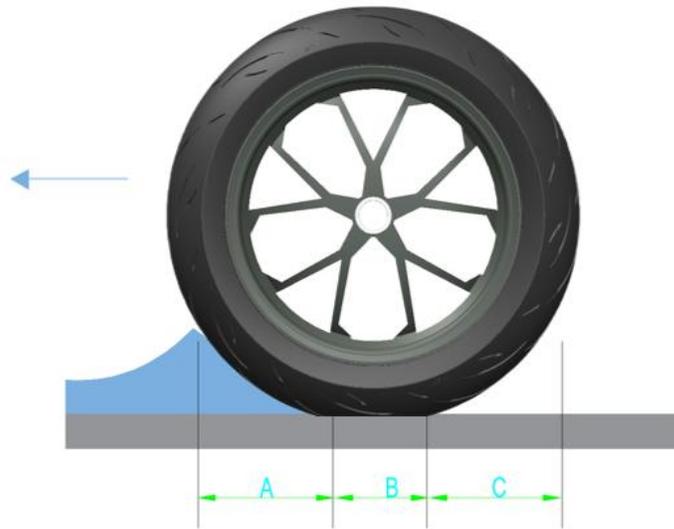


Figure 1: Aquaplaning of the tire in zones A, B, and C

In this study, the driving speeds, lateral slip angles, and directional patterns of tires with three different tread pattern designs were analyzed, the water discharge effects during contact with the wet ground were investigated by CFD analysis of STAR CCM+ software, and the results were discussed.

## 2. Materials and Methods

In this study, the water evacuation performance of 190/55 ZR17 tires with three different tread patterns was investigated. Different designs to be used in the study were coded as ANS1, ANS2, and ANS3. Table 1 includes images of currently produced tires and tread patterns.

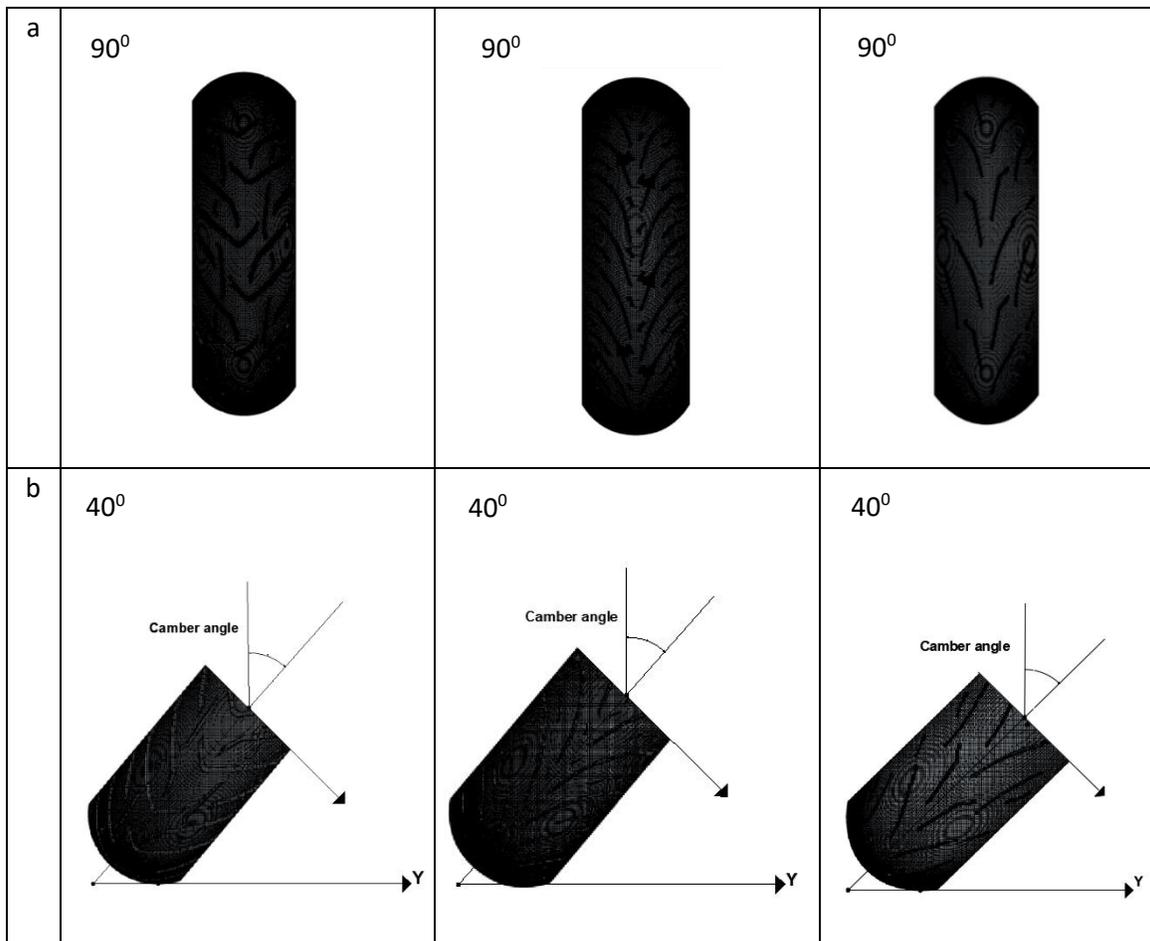
Table 1: Tires, Tread Patterns and Nomenclature to be Used for the Water Drain Test

		
ANS01	ANS02	ANS03

## 2.1. Tire Modelling

Tire mesh profiles, the contact area with  $90^\circ$  and  $40^\circ$  angles, and pattern images are shown in Table 2. A mesh image was obtained by creating polyhedral cells to capture the channel details of the tread design and provide sufficient grid resolution to examine the effects of water on the tire. The tire modelling of the tires according to the normal driving direction and the reverse driving direction is given in Figure 2.

Table 2: Mesh images of ANS01, ANS02 and ANS03; a) tire mesh image obtained at  $90^\circ$  angle, b) tire mesh image obtained at  $40^\circ$  angle, c) contact area mesh image of tire tread pattern design



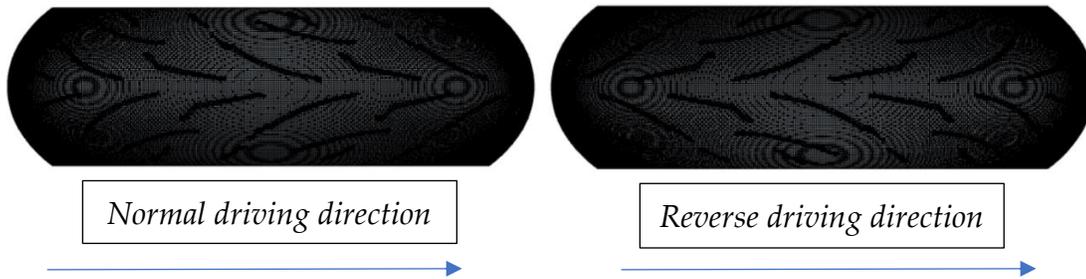
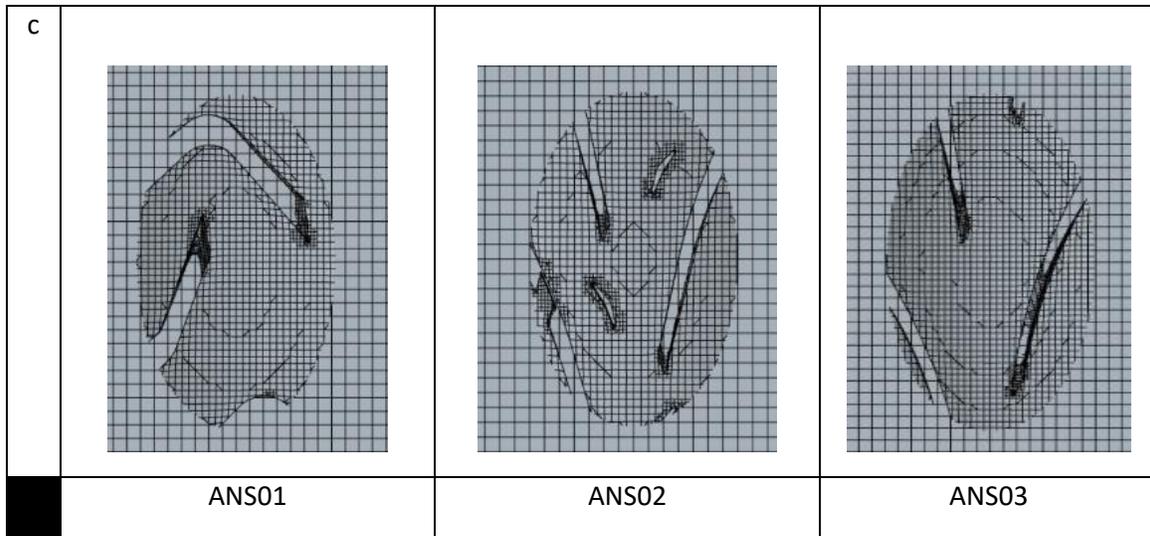


Figure 2: Tire modeling according to normal driving direction and reverse driving direction

## 2.2. Fluid Modeling Using CFD Method

In the flow model, the Navier-Stokes equations are applied considering turbulence and multiphase flow. The basic equations of fluid dynamics are based on universal conservation laws such as conservation of mass, conservation of momentum, and conservation of energy and are briefly expressed in Equations 1-3 [9].

$$\frac{\partial \rho^-}{\partial t} + \nabla \cdot (\rho^- \vec{v}^-) = 0 \quad (1)$$

$$\frac{\partial}{\partial t} \rho^- \vec{v}^- + \nabla \cdot (\rho^- \vec{v}^- \vec{v}^-) = -\nabla p + \nabla \bar{\tau} \quad (2)$$

$$\frac{\partial}{\partial t} \rho^- E + \nabla \cdot [\vec{v}^- \cdot (\rho^- E + P)] = \nabla \cdot k_{eff} \nabla T + \nabla \cdot (\bar{\tau}_{eff} \cdot \vec{v}^-) \quad (3)$$

where  $p$  is the pressure,  $\bar{\tau}$  is the fluid stress tensor,  $\vec{v}^-$  is the fluid velocity,  $E$  is the total energy, and  $k$  is the effective conductivity.

### 2.2.1. Calculation Area and Boundary Conditions

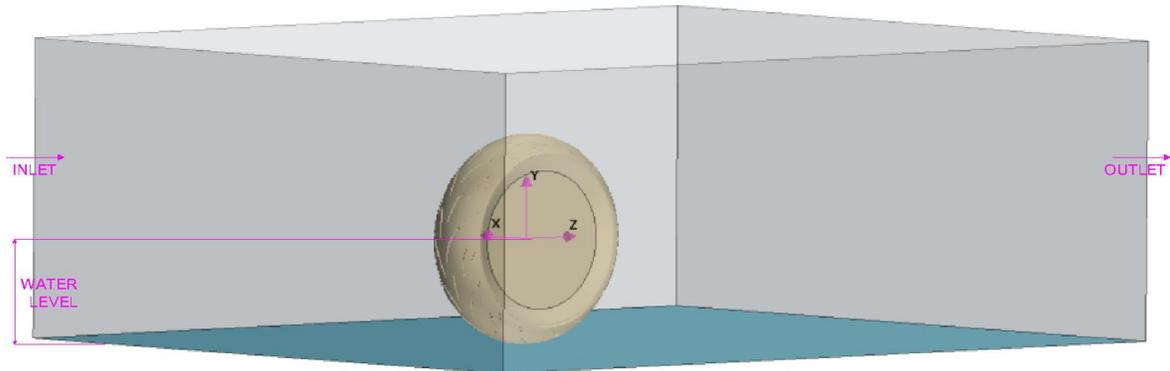


Figure 3: Diagram of the calculation area used in STAR-CCM 1

The position of the tires in the CFD region and boundary conditions is shown in Figure 3. The tires are positioned at  $90^\circ$  and  $40^\circ$  contact angles. The dimensions of the water film, formed by the software were set at  $5 \times 2000 \times 6000$  mm. Thus, a realistic water discharge simulation was created for investigated setup [4].

## 3. Results

### 3.1. Water discharge analysis

Tires with three different tread patterns (Table 1); Water discharge performance characteristics according to driving speed (60, 80, 100, 120 km/h), lateral slip angles, and pattern shape were analyzed using STAR CCM+ computational fluid dynamics CFD software.

#### 3.1.1. Effect of Speed

The results show that the water discharge performance of the three different motorcycle tires analyzed in Table 1, positioned perpendicular to the ground ( $90^\circ$ ) at different driving speeds (60, 80, 100, and 120 km/h), differs from each other.

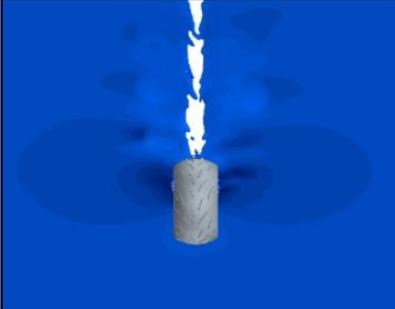
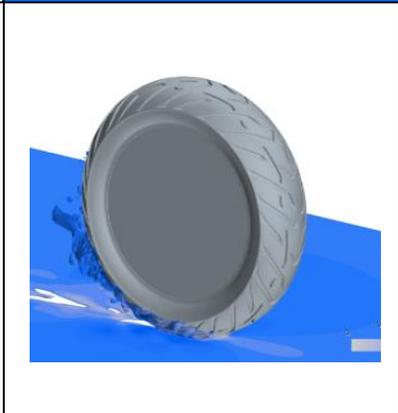
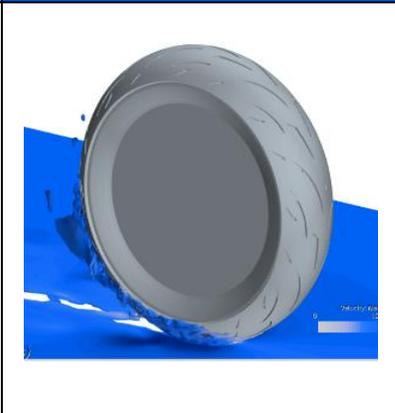
It is observed that as the driving speed increases, the water discharge performance decreases for all three patterns. This finding indicates the aquaplaning effect of water and pressure, which occurs due to the rotational speed of the tire as the speed increases. The

driving speed of the tire causes a thin layer of water to form between the tire and the ground, leading to the vehicle losing traction and slipping [10].

The water discharge performances of the three different patterns (ANS01, ANS02, and ANS03) are as follows: ANS01: ANS01<sub>60</sub>> ANS01<sub>80</sub>> ANS01<sub>100</sub>> ANS01<sub>120</sub>, ANS02: ANS02<sub>60</sub>> ANS02<sub>80</sub>> ANS02<sub>100</sub>> ANS02<sub>120</sub>, ANS03: ANS03<sub>60</sub>> ANS03<sub>80</sub>> ANS03<sub>100</sub>> ANS03<sub>120</sub>.

The findings suggest that the water discharge performance value is best achieved at a driving speed of 60 km/h for all models. For this reason, water discharge performance analyses were conducted at 60 km/h driving speed, depending on lateral slip angles and direction patterns (inverse-normal).

Table 3: Simulation views of aquaplaning on the water surface positioned at 90° at different speeds; a) top view, b) isometric view

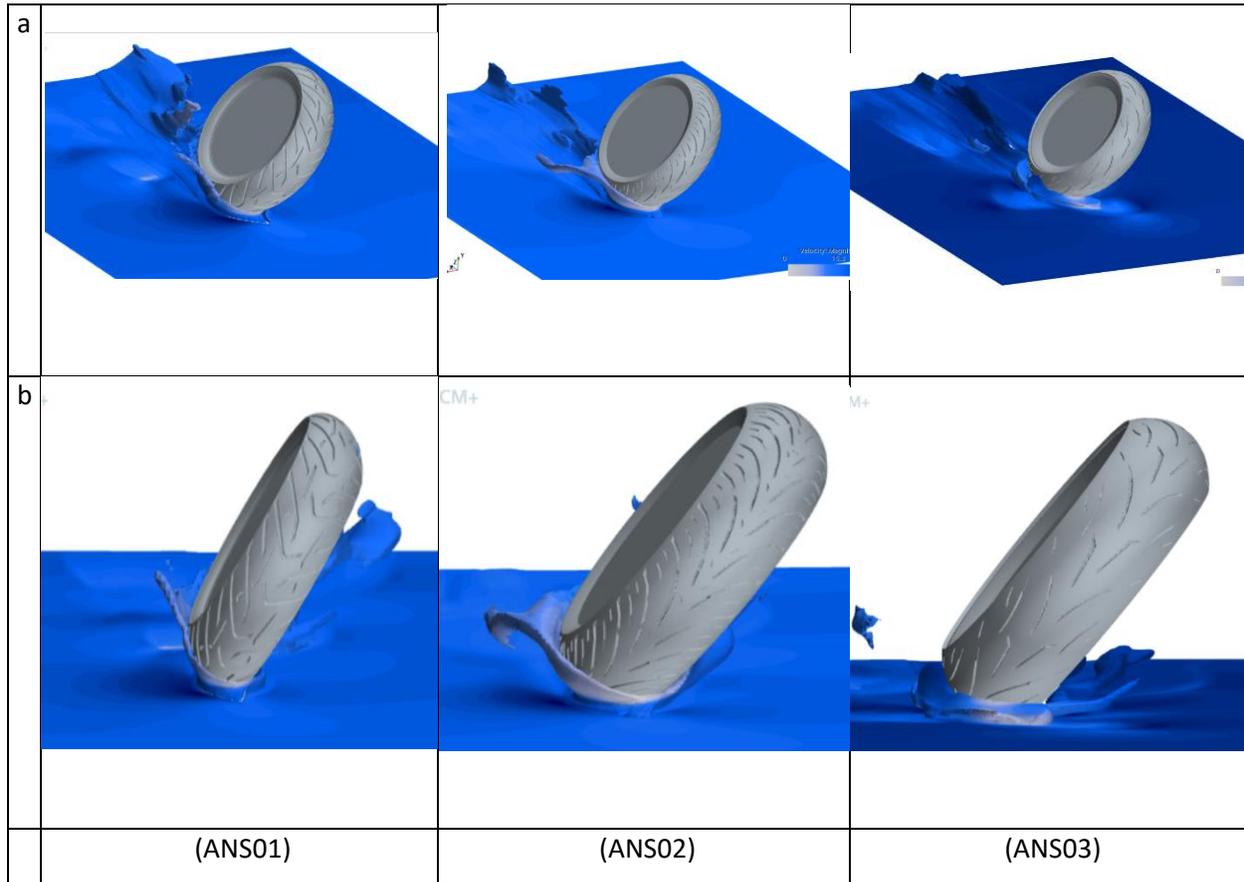
a			
b			
	(ANS01)	(ANS02)	(ANS03)

### 3.1.2. Effect of Lateral Slip Angle

Water discharge performance simulation results of motorcycle tires with three different tread patterns (ANS01-ANS02-ANS03) at 60 km/h driving speed with 40° angles are shown in Table 4. It has been observed that the water discharge performance at 60 km/h

driving speed is  $ANS01 > ANS02 > ANS03$  respectively. The tire with the ANS01 tread pattern has a better water evacuation potential than the other two tires.

Table 4: Water discharge performance simulation views at 60km/h driving speed positioned at an angle of 40°; a) isometric view, b) front view

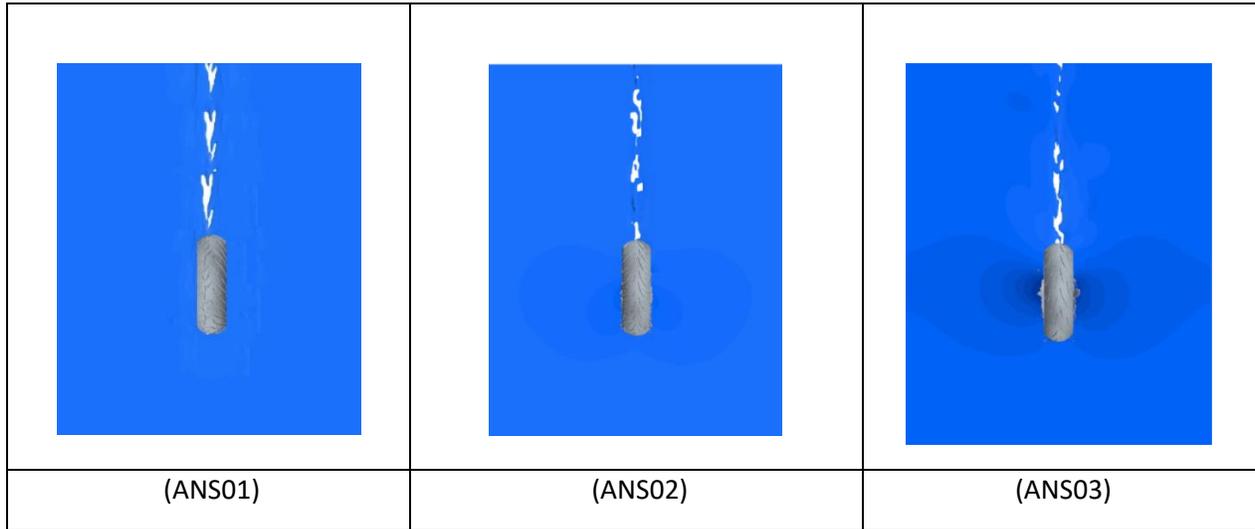


### 3.1.3. Effect of Directional Model

The simulation of motorcycle tires with ANS01-ANS02-ANS03 tread patterns in reverse driving direction at 60 km/h driving speed is shown in Table 5. As expected, the water discharge performance in the normal driving direction was higher for all tread patterns used in the study.

According to the normal and reverse driving direction, the water discharge performance is  $ANS01_{60(NORMAL)} > ANS01_{60(REVERSE)}$ ,  $ANS02_{60(NORMAL)} > ANS02_{60(REVERSE)}$ , and  $ANS03_{60(NORMAL)} > ANS03_{60(REVERSE)}$ , respectively.

Table 5: Simulation of aquaplaning at 60 km/h driving speed, top view of tire positioned in opposite driving direction.



#### 4. Discussion and Conclusion

In this study, the water discharge performance values of three motorcycle tires with different tread patterns were compared by applying the CFD technique. The obtained results can be briefly listed as follows.

- 1) The water discharge performance value, which is extremely important in tire pattern design, can be successfully calculated using STAR CCM+ computational fluid dynamics (CFD) software.
- 2) The best tire tread pattern design with wet grip performance can be made in line with customer demands before proceeding to the production stage.
- 3) Cost can be reduced in product development projects by determining the most suitable tread pattern design and minimizing the design activity.
- 4) It has been observed that there is a correlation between the water discharge performance characteristic of the tire and the driving speed, lateral slip angles and directional patterns.
- 5) The findings show that as the driving speed increases, the water discharge performance decreases for all three patterns. Obtained results reveal that the aquaplaning effect of water and pressure, which occurs depending on the rotational speed of the tire as the speed increases.
- 6) The water discharge performances of the pattern designs are examined at 400 lateral contact areas and with 60 km/h driving speed. The water discharge performance can be listed as follows:  $ANS01_{60} > ANS02_{60} > ANS03_{60}$ .
- 7) The water discharge performance values were measured at 60 km/h speed rate and it was seen that the normal driving direction performed better than the reverse driving direction.

## 5. Acknowledge

The authors' would like to thank Anlas Tyre Company, R&D Center staffs and Alper Ataseven from Iog Engineering Company for their help in the article preparation process.

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