Queensland University of Technology

Assessment of Grip Performance of Klein Handrail Sample

Client:

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Abstract

The Client (Klein Architectural Pty Ltd) manufactures handrail, formed from stainless tubing, designed to provide increased levels of grip to the user relative to plain tube handrails. This improvement would benefit users of the handrail by assisting safe passage in slippery environments, such as stairways, ramps and bathrooms.

The Client wishes to quantify the level of improvement offered by the formed design over plain tube handrails. The Consultant (Dennis De Pellegrin, Queensland University of Technology) has conducted a theoretical study to estimate this improvement, based on the geometry and surface roughness of the handrail sample provided, and published friction coefficients between skin and metal surfaces under various contamination conditions. This report includes the theory used and corresponding results and conclusions, and represents the deliverable for the consultancy project as per the Service Agreement between the Consultant and Client.

In summary, based on coefficients of friction ranging between 0.1 for oil-contaminated skin, 0.25 for dry skin and 0.5 for wet skin, and an average contact slope of 8°, it has been shown that the grip in the axial direction improves by between 1.8 and 4 times. Greatest improvement occurs when the handrail is contaminated with oil, however, it must be remembered that the absolute grip for this case is still lower than in both dry and wet conditions.

Contents

1. Introduction

The Client (Klein Architectural Pty Ltd) manufactures handrail, formed from electro-resistive welded (ERW) stainless-steel tubing, a sample of which is shown in Figure 1. Intuitively, it is expected that the novel surface form provides increased levels of grip to the user over handrails made from plain tube. This would assist safe passage in slippery environments, such as stairways, ramps and bathrooms.

The purpose of this study is to demonstrate, with the aid of theory, that this design does indeed provide increased levels of grip, and to approximately quantify the improvement.

Figure 1: Formed handrail sample

2. Theory

The theory adopted is based on the coefficient of friction, which is a measure of the limiting lateral (horizontal) force, F_H, relative to the normal (vertical) force applied to a body F_V, as shown in Figure 2.

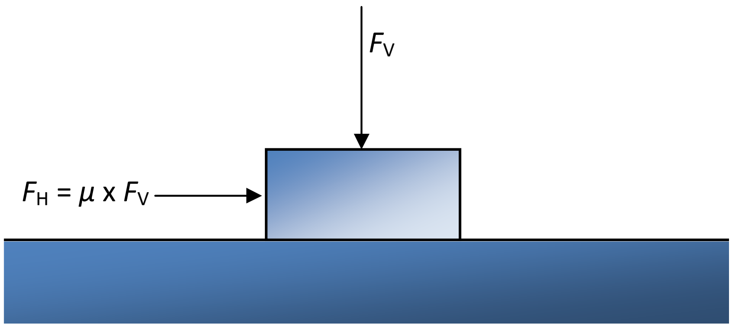


Figure 2: The relationship between forces and the coefficient of friction

The coefficient of friction μ may also be expressed as the ratio,

$$\mu = \frac{F_H}{F_V} \tag{1}$$

where μ is the dynamic coefficient of friction. Therefore F_H represents the force when sliding is in progress.

This concept may be adapted to the hand gripping a rail. The *gripping force* applied is analogous to F_v, while F_H is analogous to the force required to slide the hand axially along the rail, also defined in this work as the *grip*. Raising either the gripping force or the coefficient of friction gives rise to superior grip. In relation to the handrail, given a finite gripping force governed by the strength of the individual, grip is improved by increasing the coefficient of friction with the rail, either by changing the surface roughness or material characteristics.

An alternative way of enhancing grip is by increasing the tendency for mechanical interlocking. This is exemplified by the Klein handrail (Figure 1). The wavy profile tends to amplify the normal forces between the hand/fingers and the rail surface. This is highlighted in Figure 3. The lateral force F_{H1} necessary to slide the object along the surface is increased by the relative slope the object has to overcome.

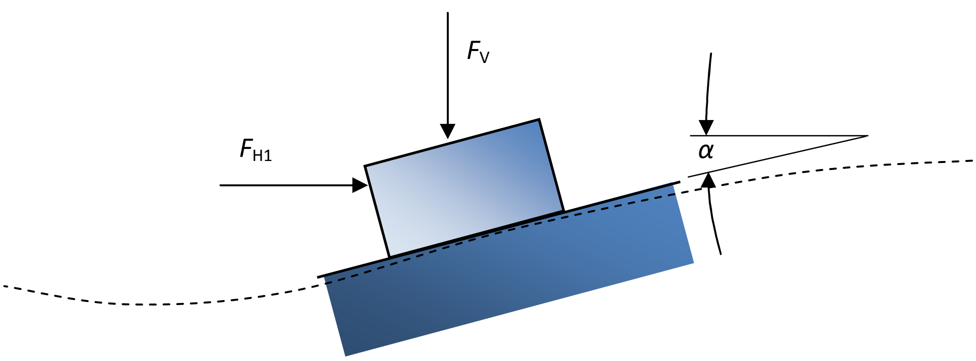


Figure 3: The concept of mechanical interlocking

It may be demonstrated that the ratio between the lateral force required in Figure 2 (F_H) and the lateral force required in Figure 3 (F_{H1}) is given by,

$$\frac{F_{H1}}{F_H} = \frac{\cos\alpha + \frac{1}{\mu}\sin\alpha}{\cos\alpha - \mu\sin\alpha} = \beta \qquad (2)$$

This ratio is henceforth also known as the *grip improvement factor, β*. The grip improvement factor is a factor that represents the number of times grip is improved over the plain-tube handrail. Theoretically, the improvement in grip, given a constant gripping force, depends on the average angle, α, of the formed handrail and the coefficient of friction between hand and rail surface, μ.

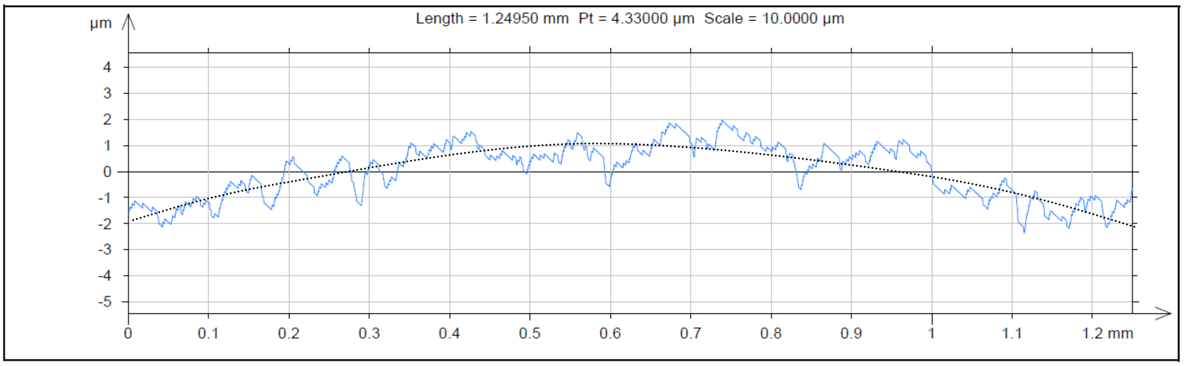
The problem reduces to estimating the average slope of the contacts and the coefficient of friction. The literature reveals that the coefficient of friction does not vary a great deal for a variety of metal and plastic materials [1] ($\mu \approx 0.2\text{-}0.3$), but it can vary far more significantly depending on contamination with water or oil [2]. Oil contaminated skin has the lowest coefficient of friction of about 0.1, dry skin about 0.25, whereas wet skin can have coefficients of friction up to 0.5 thanks to the substantial meniscal forces generated by the water droplets. These values are summarised in Table 1. The presence of excess water, however, can give rise to hydrodynamic lubrication which results in a rapid drop in the coefficient of friction (<0.1), if sliding velocities are allowed to rise significantly.

Table 1: Summary of the typical coefficients of friction between human skin and various metals and plastics

Condition	Friction coefficient μ
Oily	0.1
Dry	0.25
Wet	0.5

The surface roughness was measured at the apex of the profile in the axial direction. The surface finish is typical of a ground finish, with Ra values of between 0.2 and 0.35 µm. A typical measurement is shown in Figure 4. This is about twice as smooth as the surfaces in [1], but comparable to those in [2].

The remaining task is to identify the average slope that the hand's skin encounters against the rail surface. This is not a straightforward task given the helical form of the profile. Naturally, the various parts of the hand will see different slopes. Initially, some will even see negative slopes which are deleterious to grip performance, but any axial force sufficient to initiate slip will immediately transfer most contacts against one side of the profile valleys. From Figure 5, it is estimated that the average contact angle is 8 degrees. This represents a conservative estimate of the true average contact angle, at a position about half way up each valley.



Parameters calculated on the profile Profile

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* Parameters calculated as average value of all sampling
lengths.
* The microroughness filtering is OFF.

Roughness Parameters, Gaussian filter, 0.250000 mm

   Ra     = 0.333859 µm
            Ra: Arithmetic Mean Deviation of the roughness
profile.
   Rq     = 0.420208 µm
            Rq: Root-Mean-Square (RMS) Deviation of the
roughness profile.
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Figure 4: Surface roughness parameters at apex of profile (axial direction)

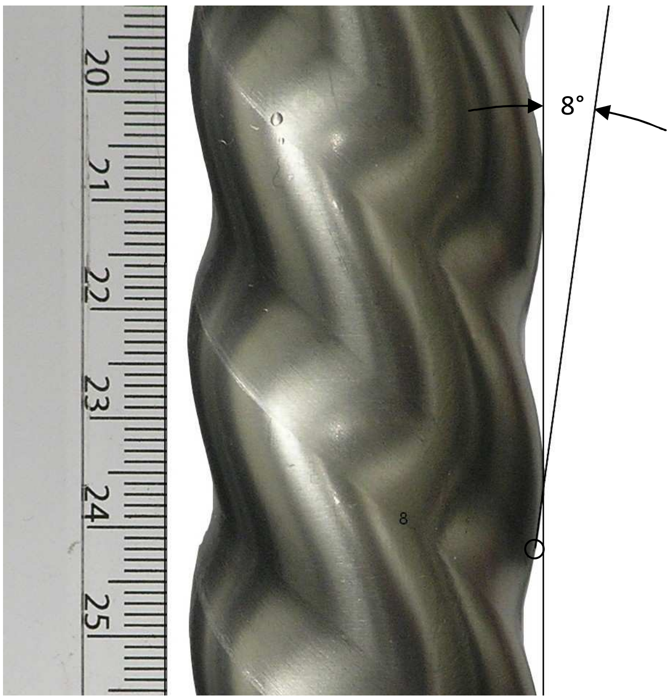

Figure 5: Estimation of the average contact angle

3. Results

From the theoretical analysis, the grip improvement factor, β, can now be calculated using Equation (2). The values of β for various angles and coefficients of friction are also shown for comparison in Table 2. It can be seen that the improvement in grip varies from 1.8 to 4 times at 8° angle. Greatest improvement occurs when the handrail is contaminated with oil, however, it must be remembered that the absolute grip force for this case is still lower than in both dry and wet conditions.

Table 2: Estimated grip improvement factors (β) for contact between human skin and various metals and plastics

		Friction coefficient μ					
		0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
Angle α [degrees]	**2**	1.7	1.4	1.3	1.2	1.2	1.2
	4	2.4	1.8	1.5	1.4	1.4	1.3
	8	4.0	2.6	2.1	1.9	1.8	1.8
	16	7.7	4.7	3.8	3.4	3.3	3.3
		Oily	**Dry**			**Wet**	

4. Conclusion

A theoretical analysis has been conducted to estimate the enhancement of grip offered by the Klein Architectural handrail sample relative to comparable plain stainless-steel tube. In conclusion:

- The analysis reveals that at least 1.8 times improvement in grip capability is obtained for the same gripping force
- This improvement is attributed to the slope of the surface which contributes to the mechanical interlocking between the rail and the hand
- This study is limited to the effect of sliding along the length (axial direction) of the rail, where improvement offers the greatest utility to users
- Some improvement in grip is also anticipated for pulling in the radial direction; however this was not quantified in the present investigation

References

[1] SE Tomlinson, R. Lewis, MJ Carre, The effect of normal force and roughness on friction in human finger contact, Wear 267 (2009) 1311-1318

[2] R Lewis, C Menardi, A Yoxall, J Langley, finger friction: Grip and opening packaging, Wear 263 (2007) 1124-1132