Feasibility study on the use of recycling materials for prototyping purposes: a comparative study based on the mechanical resistance

true

2021-02-25

First, I look for the paths of all mechanical tests

```
# Reading data ----
## Loading the paths
files <-
  here("Datos ensayos") %>%
  dir( recursive=TRUE, full.names=TRUE, pattern="\\.txt$")
```

Phase I

Then, I read the `Phase I` tests

```
# Reading the Data Fase I ----
# Selecting the Phase I
Fase.1 <- files[1:16]

## Identifying Endommage files----
  # File "PLA virgen/VE-8/VE-8.txt"

# Creating the Nested dataframe ----
Fase.I <- Fase.1 %>%  map( ~ read.delim2(.,  skip=7))
Fase.I <- Fase.I %>%   set_names(Fase.1) %>%   enframe("Type", "Data")

# Organising the dataframe
Fase.I <-
  Fase.I %>%
  separate(Type,
           sep = "/",
           into = c(c(LETTERS[1:9]), c("Phase", "Material", "Sample", "Sample name"))
  ) %>%
  select(-A, -B, -C, -D, -E, -F, -G, -H, -I)

# Arranging factors ----
Fase.I$Material <-
  factor(Fase.I$Material,
         levels = c("PLA virgen", "PLA reciclado"),
         labels = c("Virgin" , "Recycled"))
Fase.I <- Fase.I %>% arrange(Material)


# Identifying max Tensile ----
Fase.I <-
```

```
  Fase.I %>%
  mutate(#Young = map_dbl(Data,  Young ),
         Load.max = map_dbl(Data,  function(df) max(df$kN)),
         #Tensile.max = map_dbl(Data,  function(df) max(df$Tensile))
         )

## Creating the experimental dataframe with the other factors ----
### Layer height
Fase.I$LH <- c(0.15, 0.3, 0.15, 0.3, 0.3, 0.15, 0.15, 0.3, 0.15, 0.3, 0.3, 0.15, 0.3, 0.15, 0.15, 0.3)
Fase.I$LH <- as.factor(Fase.I$LH)

### Infill Pattern
Fase.I$IP <- c("Tri-hex", "Tri-hex", "Grid", "Grid",
               "Tri-hex", "Tri-hex", "Grid", "Grid",
               "Tri-hex", "Tri-hex", "Grid", "Tri-hex",
               "Tri-hex", "Grid", "Grid", "Grid")
Fase.I$IP <- as.factor(Fase.I$IP)


### Infill density
Fase.I$ID <- c(60, 60, 60, 100, 100, 100, 100, 60, 60, 60, 60, 100, 100, 60, 100, 100)
Fase.I$ID <- as.factor(Fase.I$ID)


### Printing speed
Fase.I$PS <- c(40, 80, 80, 80, 40, 80, 40, 40, 40, 80, 40, 80, 40, 80, 40, 80 )
Fase.I$PS <- as.factor(Fase.I$PS)

# Final Dataframe
Fase.I <- Fase.I %>% select(Material, LH, IP, ID, PS, Load.max , Sample, `Sample name`, Data )
```

The database of `Phase I`

```
Fase.I %>% select(Material:Load.max, Sample) %>%
  kbl(booktabs = T,
      caption = "Dataframe Phase I") %>%
  kable_styling(latex_options = "hold_position")
```

Graphic of the influence of the parameters

I create each boxplot

```
## Comparing the Virgin et Recycling
MT <-
  Fase.I %>%
  ggplot(aes(x=Material, y = Load.max )) +
  geom_boxplot(aes(fill=Material)) +
  #facet_grid( .  ~  ) +
  labs(y="Max Load [kN]", x="Material type") +
  coord_cartesian(ylim = c(1, 4))

## Comparing the Virgin et Recycling
LH <-
  Fase.I %>%
  ggplot(aes(x = LH, y = Load.max )) +
```

Table 1: Dataframe Phase I

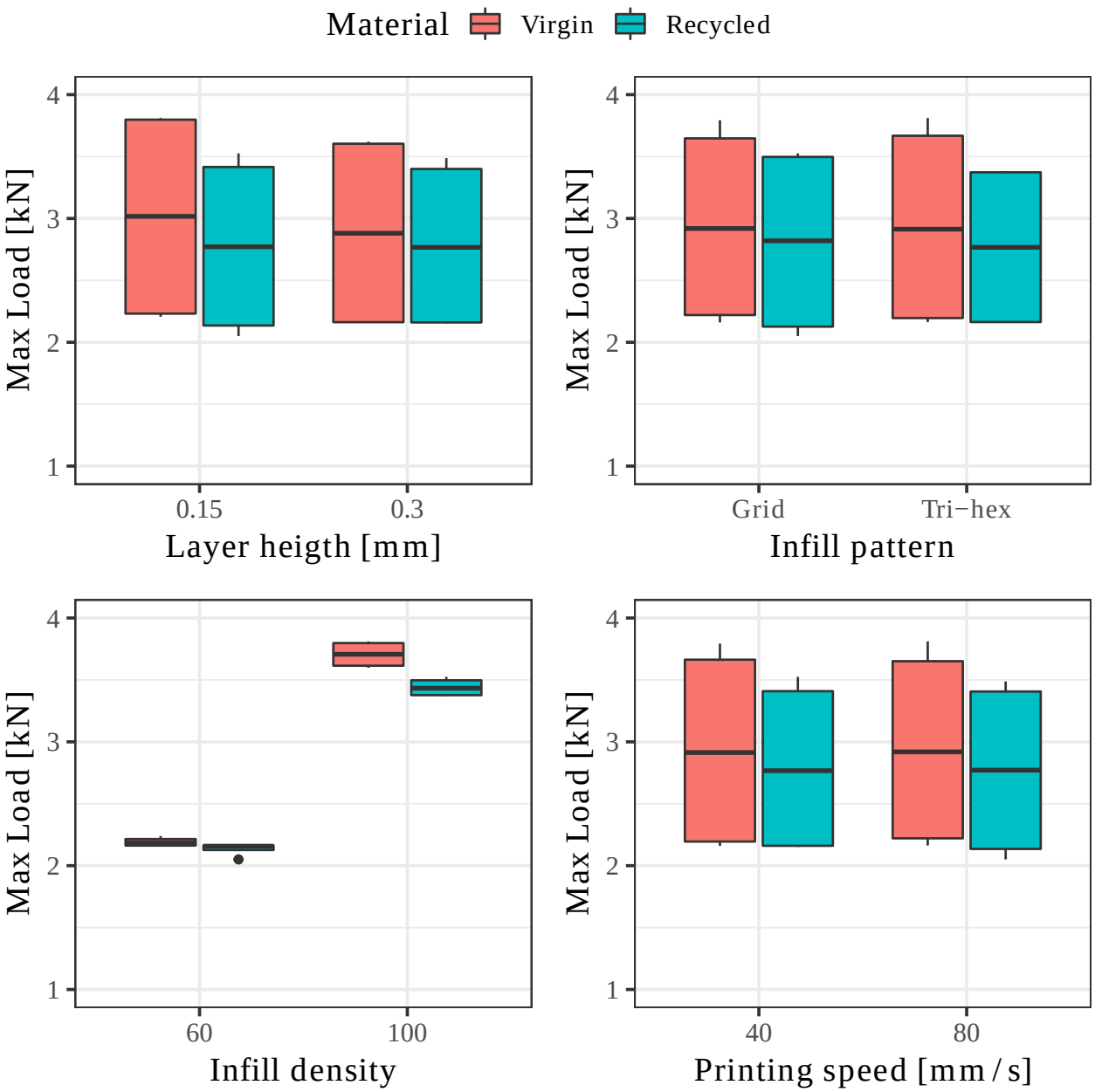
Material	LH	IP	ID	PS	Load.max	Sample
Virgin	0.15	Tri-hex	60	40	2.206447	VE-1
Virgin	0.3	Tri-hex	60	80	2.163030	VE-2
Virgin	0.15	Grid	60	80	2.239898	VE-3
Virgin	0.3	Grid	100	80	3.597994	VE-4
Virgin	0.3	Tri-hex	100	40	3.620359	VE-5
Virgin	0.15	Tri-hex	100	80	3.811253	VE-6
Virgin	0.15	Grid	100	40	3.793354	VE-7
Virgin	0.3	Grid	60	40	2.160100	VE-8
Recycled	0.15	Tri-hex	60	40	2.163397	RE-1
Recycled	0.3	Tri-hex	60	80	2.163340	RE-2
Recycled	0.3	Grid	60	40	2.151576	RE-3
Recycled	0.15	Tri-hex	100	80	3.379278	RE-4
Recycled	0.3	Tri-hex	100	40	3.370447	RE-5
Recycled	0.15	Grid	60	80	2.050518	RE-6
Recycled	0.15	Grid	100	40	3.525304	RE-7
Recycled	0.3	Grid	100	80	3.487604	RE-8

```
  geom_boxplot(aes(fill=Material)) +
  #facet_grid( .  ~  ) +
  labs(y="Max Load [kN]", x="Layer heigth [mm]") +
  coord_cartesian(ylim = c(1, 4))

## Infill pattern
IP <-
  Fase.I %>%
  ggplot(aes(x = IP, y = Load.max )) +
  geom_boxplot(aes(fill=Material)) +
  #facet_grid( .  ~  ) +
  labs(y="Max Load [kN]", x="Infill pattern") +
  coord_cartesian(ylim = c(1, 4))

## Infill density
ID <-
  Fase.I %>%
  ggplot(aes(x = ID, y = Load.max )) +
  geom_boxplot(aes(fill=Material)) +
  #facet_grid( .  ~  ) +
  labs(y="Max Load [kN]", x="Infill density") +
  coord_cartesian(ylim = c(1, 4))

## Infill density
PS <-
  Fase.I %>%
  ggplot(aes(x = PS, y = Load.max )) +
  geom_boxplot(aes(fill=Material)) +
  #facet_grid( Load.max  ~ LH + IP ) +
  labs(y="Max Load [kN]", x="Printing speed [mm/s]") +
```

```
  coord_cartesian(ylim = c(1, 4))
```

Plotting the Boxplots

```
ggarrange(LH, IP, ID , PS,  ncol = 2, nrow = 2 ,common.legend = TRUE)
```




```
#ggsave("../Figures/Phase-1-2.jpg", width=6, height=6, dpi = "print")
```

Anova Phase I

```
## Creating the Linear Model without interactions
Fase.I_anova <- Fase.I %>% select(Material:PS, Load.max)
Total_model <- lm(Load.max ~ LH+IP+ID+PS+Material , data = Fase.I_anova)
#summary(Total_model)
```

Table 2: ANOVA results at 95% significance level

	Df	Sum Sq	Mean Sq	F value	Pr(F)
LH	1	0.0	0.013	1.340	0.274
IP	1	0.0	0.001	0.107	0.750
ID	1	8.0	7.963	824.810	0.000
PS	1	0.0	0.001	0.062	0.808
Material	1	0.1	0.106	10.957	0.008
Residuals	10	0.1	0.010	NA	NA

Table 3: ANOVA Virgin

	Df	Sum Sq	Mean Sq	F value	Pr(F)
LH	1	0.0	0.032	10.264	0.049
IP	1	0.0	0.000	0.004	0.955
ID	1	4.6	4.581	1449.011	0.000
PS	1	0.0	0.000	0.040	0.854
Residuals	3	0.0	0.003	NA	NA

```
anv.fase.1 <- anova(Total_model)
```

```
# Plotting Anovoa table
anv.fase.1 %>%  set_names("Df", "Sum Sq", "Mean Sq", "F value", "Pr(F)") %>%
  kbl(booktabs = T, digits = c(0, 1, 3, 3, 3, 5),
      caption = "ANOVA results at 95\\% significance level",
      linesep = "")  %>%
  kable_styling(latex_options = c("striped"))
```

Anova Phase I - Virgin and Recycled

```
## Virgin
Virgen <- Fase.I %>% filter(Material == "Virgin") %>% select(LH:PS, Load.max)
Virgin_model <- lm(Load.max ~ . , data =Virgen )
Virgin_anova <- anova(Virgin_model)

## Recycled
Recycled <- Fase.I %>% filter(Material == "Recycled") %>% select(LH:PS, Load.max)
Recycled_model <- lm(Load.max ~ . , data =Recycled)
Recycled_anova <- anova(Recycled_model)
```

Anova for Virgin material

```
Virgin_anova %>%  set_names("Df", "Sum Sq", "Mean Sq", "F value", "Pr(F)") %>%
  kbl(booktabs = T, digits = c(0, 1, 3, 3, 3, 5),
      caption = "ANOVA Virgin",
      linesep = "")  %>%
  kable_styling(latex_options = c("striped"))
```

Anova for Recycled material

Table 4: ANOVA Recycled

	Df	Sum Sq	Mean Sq	F value	Pr(F)
LH	1	0.0	0.000	0.050	0.837
IP	1	0.0	0.002	0.325	0.609
ID	1	3.4	3.424	463.252	0.000
PS	1	0.0	0.002	0.286	0.630
Residuals	3	0.0	0.007	NA	NA

```
Recycled_anova %>% set_names("Df", "Sum Sq", "Mean Sq", "F value", "Pr(F)") %>%
  kbl(booktabs = T, digits = c(0, 1, 3, 3, 3, 5),
      caption = "ANOVA Recycled",
      linesep = "")  %>%
  kable_styling(latex_options = c("striped"))
```

Phase II

Identifying the Paths

```
# Selecting the Phase II----
Fase.2 <- files[17:27]
# Deleting test repetido Recycled 70-RE
Fase.2 <- Fase.2[-4]


# Files missing:``
# PLA reciclado/40-RE.txt

# Reading the Data Fase II ----
## Identifying missing data
Fase.II <- Fase.2 %>%  map( ~ read.delim2(.,  skip=7))
Fase.II <- Fase.II  %>%   set_names(Fase.2) %>%   enframe("Type", "Data")

# Organising datafram ----
Fase.II <-
  Fase.II %>%
  separate(Type,
           sep = "/",
           into = c(c(LETTERS[1:9]), c("Phase", "Material", "Sample", "Sample name"))
  ) %>%
  select(-A, -B, -C, -D, -E, -F, -G, -H, -I)

# Arranging factors ----
Fase.II$Material <-
  factor(Fase.II$Material,
         levels = c("PLA virgen", "PLA reciclado"),
         labels = c("Virgin" , "Recycled"))

Fase.II <- Fase.II %>% arrange(Material)

# Calculating max Values ----
Fase.II <-
```

Table 5: Dataframe Phase II

Material	ID	Load.max
Virgin	100	3.289401
Virgin	40	1.871928
Virgin	55	1.980000
Virgin	70	2.145087
Virgin	85	2.295690
Recycled	100	3.029757
Recycled	40	1.800000
Recycled	55	1.930000
Recycled	70	2.082841
Recycled	85	2.241600

```
  Fase.II %>%
  mutate(Load.max = map_dbl(Data,  function(df) max(df$kN)),
         )

# Creating final dataframe of Phase II
Fase.II <-
  Fase.II %>%
  separate(Sample,
           sep = "-",
           into = c("ID", "Material2")) %>%
  select(Material, ID, Load.max)

# As factor the the variables ID
Fase.II$ID <- as.numeric(Fase.II$ID)
```

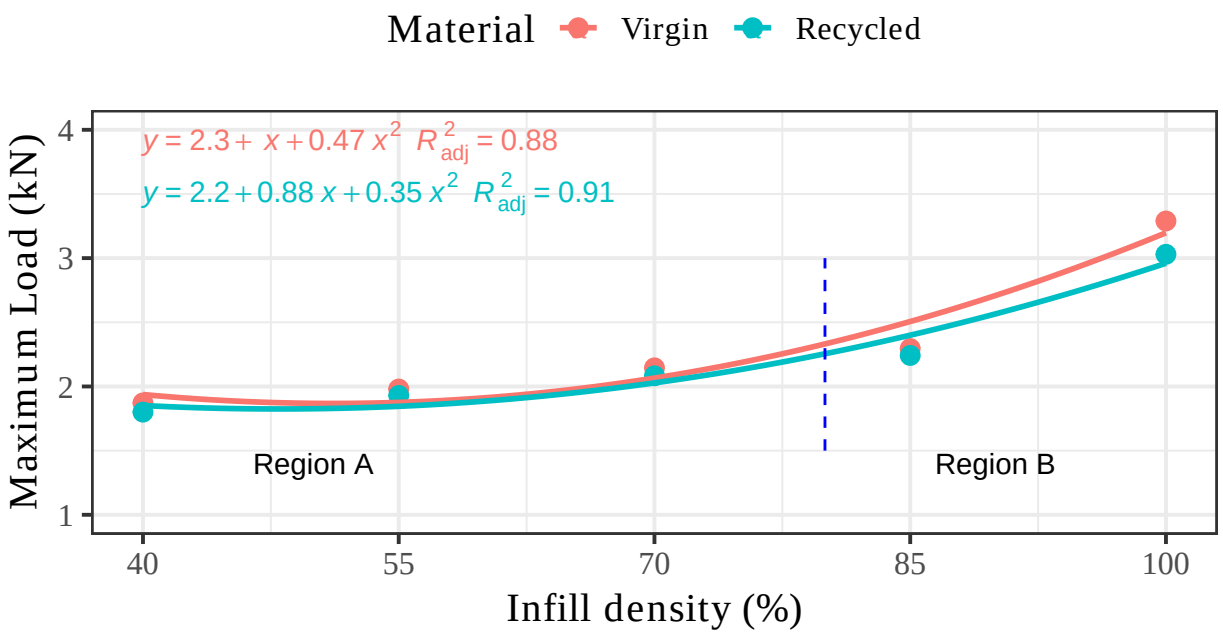
The database of `Phase II`

```
Fase.II %>%
  kbl(booktabs = T,
      caption = "Dataframe Phase II",
      linesep = "")  %>%
  kable_styling()
```

Ploting the Graph comparative

```
ggplot(Fase.II, aes(x=ID, y=Load.max, col=Material)) +
  geom_point(aes(col=Material) ,size=3) +
  stat_smooth(method = "lm", formula = y ~ poly(x, 2), se=FALSE) +
 stat_regline_equation(label.y = c(3.9,3.5), label.x = c(40,40) , data = Fase.II, aes(x=ID, y=Load.max,
  annotate("segment", x = 80, xend = 80, y = 1.5, yend = 3,  colour = "blue", linetype = "dashed") +
  coord_cartesian(xlim=c(40, 100), ylim=c(1, 4)) +
  scale_x_continuous(breaks = c(40, 55, 70, 85, 100)) +
  annotate("text", x = c(50, 90), y = 1.4, label = c("Region A", "Region B"))+
  labs(title="",
       subtitle="",
       caption="",
       y="Maximum Load (kN)",
       x="Infill density (%)" ) +
```

```
theme(legend.position="top")
```




```
#ggsave("../Figures/Phase-2.jpg", width=5, height=5, dpi = "print")

# Calculating the reductions
#Fase.II %>% group_by(ID) %>% summarise(media = mean(Load.max),                    sd
#100- (1.84 * 100)/3.16
```

Phase III

Identifying the paths

```
# Selecting the Phase III----
Fase.3 <- files[28:57]

# Deleting test repetido Recycled 70-RE
Fase.3 <- Fase.3[1:30]

# Files missing:
#

# Reading the Data Fase II ----
## Identifying missing data
Fase.III <- Fase.3 %>%  map( ~ read.delim2(.,  skip=7))
Fase.III <- Fase.III  %>%   set_names(Fase.3) %>%   enframe("Type", "Data")
#Fase.III

# Organising dataframE ----
Fase.III <-
  Fase.III %>%
  separate(Type,
           sep = "/",
           into = c(c(LETTERS[1:10]), c("Material", "Orientation", "Sample", "Sample name"))
  ) %>%
```

```
  select(-A, -B, -C, -D, -E, -F, -G, -H, -I,-J)

# Arranging factors ----
Fase.III$Material <-
  factor(Fase.III$Material,
         levels = c( "Virgen", "Reciclado"),
         labels = c( "Virgin", "Recycled" ))

Fase.III$Orientation <- tolower(Fase.III$Orientation)
Fase.III$Orientation <-
  factor(Fase.III$Orientation,
         levels = c("horizontal", "vertical", "canto"),
         labels = c("Horizontal" , "Vertical", "Edgewise"))


Fase.III <- Fase.III %>% arrange(Material)

# Calculating max Values ----
Fase.III <-
  Fase.III %>%
  mutate(Load.max = map_dbl(Data,  function(df) max(df$kN)),
         )

# Creating final dataframe of Phase II
Fase.III <-
  Fase.III %>%
  select(Material, Orientation, Load.max)
```

The database of `Phase III`

```
Fase.III %>%
  kbl(booktabs = T,
      caption = "Dataframe Phase III",
      linesep = "")  %>%
  kable_styling()
```

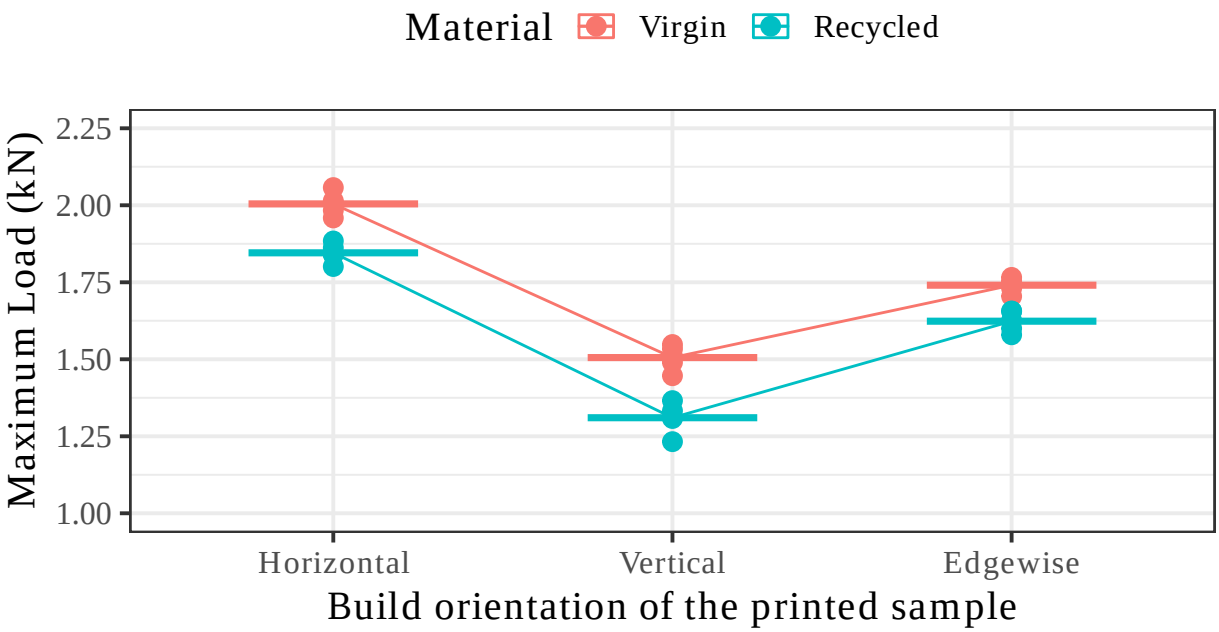
```
# Grafica -----

#Fase.III <-
Fase.III %>%
  ggplot(aes(x=Orientation, y=Load.max, colour = Material, group=Material)) +
  geom_point(size=3) +
  #aes(colour = Material) +
  stat_summary(fun = mean, geom="line") +
  stat_summary(fun = mean, geom="crossbar", width=0.5) +
  labs(title="",
       subtitle="",
       caption="",
       y="Maximum Load (kN)",
       x="Build orientation of the printed sample" ) +
  theme(legend.position="top") +
  coord_cartesian(ylim=c(1, 2.25)) +
  scale_y_continuous(limits = c(1, 2.25), breaks = c(1, 1.25, 1.5, 1.75, 2, 2.25))
```

Table 6: Dataframe Phase III

Material	Orientation	Load.max
Virgin	Edgewise	1.747823
Virgin	Edgewise	1.765820
Virgin	Edgewise	1.730427
Virgin	Edgewise	1.704503
Virgin	Edgewise	1.753934
Virgin	Horizontal	1.958976
Virgin	Horizontal	1.983678
Virgin	Horizontal	2.014734
Virgin	Horizontal	2.007786
Virgin	Horizontal	2.057465
Virgin	Vertical	1.547935
Virgin	Vertical	1.446656
Virgin	Vertical	1.533726
Virgin	Vertical	1.489762
Virgin	Vertical	1.509607
Recycled	Edgewise	1.656769
Recycled	Edgewise	1.626131
Recycled	Edgewise	1.579502
Recycled	Edgewise	1.655694
Recycled	Edgewise	1.600046
Recycled	Horizontal	1.801188
Recycled	Horizontal	1.861987
Recycled	Horizontal	1.840000
Recycled	Horizontal	1.884053
Recycled	Horizontal	1.841062
Recycled	Vertical	1.365745
Recycled	Vertical	1.312332
Recycled	Vertical	1.232536
Recycled	Vertical	1.307808
Recycled	Vertical	1.332666

Table 7: Reduction of properties according to orientation

Orientation	Virgin	Recycled	reduction
Horizontal	2.004528	1.845658	7.925555
Vertical	1.505537	1.310217	12.973422
Edgewise	1.740501	1.623629	6.714894




```
#ggsave("../Figures/Phase-3.jpg", width=5, height=5, dpi = "print")
```

Reduction of the load values

```
## Calculating the reduction
Reduction <-
  Fase.III %>%
  group_by(Material,Orientation) %>%
  summarise(media = mean(Load.max))
```

```
## `summarise()` has grouped output by 'Material'. You can override using the `.groups` argument.
```

```
Reduction <- Reduction %>% pivot_wider(names_from = Material, values_from = media)
Reduction <- Reduction %>% mutate(reduction = (100 - Recycled*100/Virgin ) )

Reduction %>%
  kbl(booktabs = T,
      caption = "Reduction of properties according to orientation",
      linesep = "")  %>%
  kable_styling()
```

Exporting Tables

```
## Write
#write_csv2(Fase.I, "Phase-1.csv")
#write_csv2(Fase.II, "Phase-2.csv")
```

```
#write_csv2(Fase.III, "Phase-3.csv")
```